RoutineAid: Externalizing Key Design Elements to Support Daily Routines of Individuals with Autism

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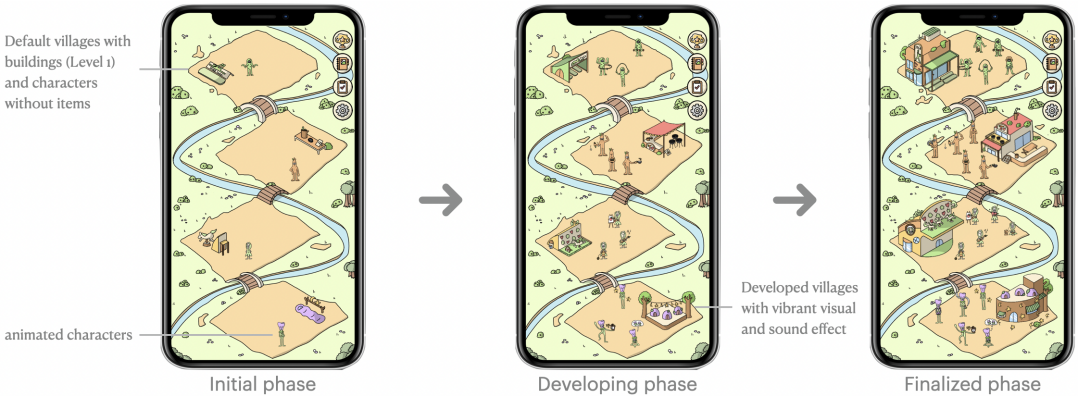

Figure 1: The progress levels in RoutineAid. Users can experience building upgrades and item acquisition as they establish and maintain self-directed routine structures. The obtained items are presented as animated actions of characters.

ABSTRACT

Implementing structure into our daily lives is critical for maintaining health, productivity, and social and emotional well-being. New norms for routine management have emerged during the current pandemic, and in particular, individuals with autism find it difficult to adapt to those norms. While much research has focused on the use of computer technology to support individuals with autism, little is known about ways of helping them establish and maintain "self-directed" routine structures. In this paper, we identify design requirements for an app that support four key routine components (i.e., physical activity, diet, mindfulness, and sleep) through a formative study and develop *RoutineAid*, a gamified smartphone app that reflects the design requirements. The results of a two-month field study on design feasibility highlight two affordances of *RoutineAid*—the establishment of daily routines by facilitating micro-planning and the maintenance of daily routines through celebratory interactions. We discuss salient design considerations for the future development of daily routine management tools for individuals with autism.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility systems and tools**.

KEYWORDS

autism, daily routine management, mobile game, user study

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1 INTRODUCTION

The maintenance of daily routine is important to everyone and can affect physical, emotional, and social well-being [30]. At the height of the COVID-19 pandemic, people around the world experienced significant restrictions in maintaining their daily routines [46]. Rates of depression have risen due to self-isolation and

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social distancing [30]. Such restrictions have particularly affected individuals with autism. Recent studies have reported increased instances of impulsive aggression, high anxiety, and other challenging behaviors of autistic individuals due to the suspension of both school classes and essential medical and social services that they are used to receiving [13]. Although several pleasant changes for individuals with autism also resulted from the pandemic (e.g., an increase in solidarity and reduced sensory and social overload), reduced access to medical/social services and the loss of routines have had a unique impact on individuals with autism [50]. According to a United Nations report [24], the world's one billion people with disability were severely affected by the pandemic (e.g., through a lack of accessible public health information, significant barriers to implementing basic hygiene measures), yet government agencies supported only 28% of people with severe disabilities and only 1% in low-income countries. Furthermore, autism-specific guidance is critically needed, as the current regular care system is insufficient to meet the needs of autism communities [4].

Various computer-assisted programs have been suggested to promote physical, emotional, and social well-being [32, 33, 39]. In particular, smartphone-based programs have been found to be effective in establishing and maintaining healthy habits, as the programs assist users in setting behavioral goals, monitoring target behaviors, and planning actions in a timely manner [34, 35]. However, essential routine elements and strategies for sustaining routine practices among autistic individuals have not yet been established, and the effectiveness of existing off-the-shelf smartphone apps (e.g., First Then Visual Schedule [21], Fun Routine [52]) for individuals with autism is not clear. Thus, our research aim is to identify key design requirements and develop a smartphone-based health intervention program that can support autistic individuals in establishing and maintaining their everyday routines disrupted by the pandemic.

In this work, we identified the following three challenges relevant to daily routine management through a formative study of 15 autism stakeholders (e.g., autism professionals involved in diagnosis advice and support, parents of individuals with autism, and individuals with autism). First, individuals with autism have been facing amplified anxiety due to a broken routine. Second, they have insufficient support to balance key components of daily routines (e.g., physical activities, eating habits, mindfulness, and sleep). Finally, they have frequent difficulties in planning concrete and actionable measures to sustain their routines. We formulated three design goals corresponding to each challenge: (1) provide opportunities to explore and plan appropriate life rhythms with visual narratives, (2) provide opportunities to achieve sustainable key daily routine management, and (3) provide opportunities to explore actionable daily routine planning.

Based on these goals, we developed *RoutineAid*, a gamified smartphone app designed to break down daily routines into smaller steps and celebrate the accomplishment of each. Users can perform key and secondary daily routines and develop four types of villages (physical activity, eat, mindfulness, and sleep) through building upgrades and item acquisition based on the progress of their routine quests. In addition, daily routine logs (called routine diary) and the leaderboard are offered to facilitate users' self-reflection. With *RoutineAid*'s gameplay, users are expected to be able to independently manage their routines and know the essential components of their own healthy life patterns.

To examine the feasibility of *RoutineAid*, we conducted a two-month field study with 10 participants with autism. From the study results, we observed two affordances of *RoutineAid*: (1) the establishment of daily routines by facilitating microplanning and (2) the maintenance of daily routines through celebratory interactions (e.g., acknowledging achievements through a leaderboard, visual feedback on the completion of microtasks, gradual acquisition of rewards). In particular, routine quests that encourage self-reflection and have visual narratives and gamified elements greatly motivated the participants to use the app. The participants had an opportunity to observe their routines from various angles by performing the recommended and personalized routine quests.

To summarize, this paper makes the following contributions:

- We identify key design goals for the development of a routine management system for individuals with autism from a formative study and introduce a smartphone app, *RoutineAid* that supports those goals.
- We demonstrate the feasibility of *RoutineAid* in managing routine by individuals with autism from a two-month field study, operationalized by the following two affordances of *RoutineAid*: the establishment of daily routines by facilitating micro-planning and the maintenance of daily routines through celebratory interactions.
- We present six salient design implications for routine management: (1) providing routine quests adaptive to a user's context, progress, and preferences, (2) balancing self-directed behaviors and experts' regular interventions for long-term routines management, (3) leveraging visual elements of the main screen to trigger enhanced user engagement, (4) beyond a rank-focused leaderboard, (5) visual support considering loss aversion, and (6) possible data use in clinical settings and data privacy concerns.

2 RELATED WORK

2.1 Leveraging Mobile Technology to Support Routine Management for Individuals with Autism

Due to the COVID-19 outbreak, individuals with autism are experiencing greater difficulty in maintaining their physical and emotional well-being [51]. Disrupted routines elicit major emotional and behavioral challenges (e.g., an irregular wake-up rhythm, a high level of sedentary behavior) [18] since individuals with autism prefer a standardized routine and are reluctant to adapt to sudden changes. The suspension and reduction of care or specialized educational programs for individuals with autism due to the need for social distancing during the pandemic aggravated their difficulties. Thus, additional support is critically needed to help them overcome such difficulties.

Many welfare centers and hospitals have suggested strategies to manage a healthy routine and have suggested structured and specific guidelines for sustaining such a routine [5, 49]. The guidelines recommend (1) scheduling a physical activity time, (2) creating a regular routine (e.g., regular sleep, regular intake of meals), and (3) maintaining a daily stress-relief time (e.g., writing a daily diary,

meditating). Researchers have also explored how, during the pandemic, information technology supported individuals with autism in healthcare and education [16, 54]. Their studies demonstrated the effectiveness of smartphone systems, such as mobile applications on users' physical and mental well-being [42, 47]. As mobile and wearable devices can offer personalized information systems with interactive visual materials and embedded sensors (e.g., camera, GPS), studies have been conducted to explore how individuals with autism self-manage their physical and mental well-being with these smart devices [34, 35, 43].

Previous research has reported that the process of tracking and reflecting personal data on smartphone apps provides an opportunity to understand autistic individuals' physical [9] and mental conditions [35]. For instance, in a study on PuzzleWalk [34], a gamified mobile app devised to promote physical activities in adults with autism, the users were asked to perform physical activity to continue solving the puzzle game in the app, and their step counts were converted into additional gameplay time. The results of the study revealed that the users were motivated to increase their physical activity through the gamification elements of the app. In a study of five adolescents with autism [35], a custom self-tracking platform was employed to help them better understand the causes and consequences of, as well as their feelings around their circumstance. The results of the study revealed that the use of this flexible and scaffolded self-tracker helped them effectively navigate their negative emotions. However, prior studies have focused on a single objective related to individuals with autism, which is somewhat limited to understand and find ways to support their daily routine management. As individuals with autism are likely to have different goals, preferences, and priorities regarding their routine types; it is important to look into their routines from broader perspectives, identify key routine components, and provide them with the opportunity to become aware of, navigate, and manage those components on their own [48]. This will lead to a better understanding of how to use technology to support and maintain the daily routine of individuals with autism [39].

Individuals with autism can access a variety of apps (e.g., First Then Visual Schedule [21], Fun Routine [52]) for routine management in commercial stores (e.g., Google Play Store, Apple App Store). There are even some apps designed for children with autism to effectively support executive function impairments. However, the effectiveness of these apps is questionable. The routine types are limited to simple wake-up or bedtime rituals (e.g., washing the face, brushing the teeth) and lack the support of diverse routines as well as the motivation to participate [21, 52]. As for routine management apps for the general population, they appear to pose high entry barriers for individuals with autism. For example, Habitica [25], a gamified habit-forming app, requires users to do much work (e.g., define good or bad habits and set a level of difficulty when performing each habit) without providing sufficient guidelines. As such, current commercial apps for routine management for this user group do not seem to provide them with explicit action items and, thus, tend to make autistic individuals feel burdened [31, 44]. Through *RoutineAid*, we provide opportunities for individuals with autism to explore diverse factors associated with each routine component in the form of elaborate, actionable, and achievable guidance called routine quests.

2.2 The Use of Gamification and Visual Narrative for Individuals with Autism

Gamification is defined as "the use of game design elements in non-game contexts." Gamified mobile apps can enhance users' intrinsic motivation by using game-like elements, such as animated characters, problem-solving, and engaging storylines [15]. These elements have been used in computer-based health interventions or for serious game development for individuals with autism (e.g., for their social skills training [55], stress and anxiety management [10]). Whyte et al. [58] reviewed studies on serious game interventions for individuals with autism and presented a design framework of how gamification elements can be effectively applied in the design process. The results of the study highlighted the importance of a solid and immersive "narrative storyline" (e.g., contextualizing learning experiences via a motivating storyline) to effectively link gamification to the goal-setting process and achievement of the intervention. In addition, much research has shown that individuals with autism have a high preference for visual narratives [8, 34, 55]. For example, Beaumont et al. [8] employed "Junior detective," a narrative-based computer game designed to allow children with autism to practice human emotion recognition. The children learned how to recognize complex emotions (e.g., guilt, embarrassment, suspicion, and teasing) of computer-animated and human characters. The game resulted in significant improvements in the social functioning of 26 children with autism. Tang et al. [55] conducted a game development study to promote emotion recognition skills in young adults with autism. This study confirmed not only the effectiveness of gamification but also the preference of young adults with autism for immersive and visual narratives with a clear end goal.

As such, the effectiveness of gamification elements and visual narratives in designing mobile apps for individuals with autism has been proven. However, few studies have considered the aforementioned preferences or needs of autistic people in the design of a gamified app for routine management. The current pandemic has significantly highlighted the importance of routine management, especially for individuals with autism, but ways of effective support through computer technology have not been sufficiently explored. Previous studies on individuals with autism underscored the importance of participatory design-based research, which supports the intrinsic motivation of autism stakeholders and considers their embodied experiences in the development of technologies [20, 34]. Moreover, a survey on HCI games for individuals with autism [52] revealed that the provision of only externally driven play experiences without support for the autonomy and relevance of individuals with autism leads to the marginalization of the potential immersion and enjoyment of autistic people. To address these findings, in this study, we identified the key design goals for a routine management app for autistic people through a formative study with autism stakeholders (e.g., autism professionals, parents of an individual with autism, and individuals with autism). We implemented *RoutineAid* based on those goals, empirically examined how individuals with autism manage their daily routines with *RoutineAid*, and identified additional salient insights for better supporting their routine through a two-month field study.

Group	Code	Gender	Age	Job Description
Autism professionals	FA1	Female	41	Child and adolescent psychiatrist, 15+ years of experience (exp.)
	FA2	Female	31	Behavioral therapist/Special education teacher, 5+ exp.
	FA3	Male	38	Child and adolescent psychiatrist, 10+ exp.
	FA4	Female	33	Behavioral therapist, 7+ exp.
	FA5	Female	52	Director of welfare center for people with disabilities, 25+ exp.
Parents of an individual with autism	FP1	Female	50	N/A
	FP2	Female	54	
	FP3	Female	52	
	FP4	Female	59	
	FP5	Male	53	
Individuals with autism	FI1	Male	32	Public assistant librarian
	FI2	Male	31	Office worker
	FI3	Male	24	College student
	FI4	Male	22	Kitchen assistant
	FI5	Male	21	Assistant baker

Table 1: Demographics of formative study participants ("F" = formative study).

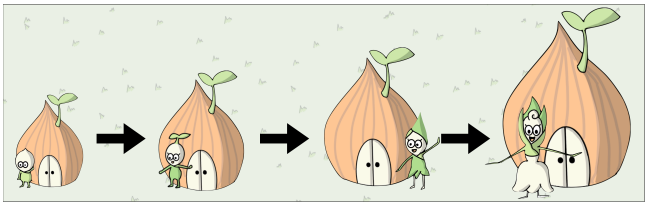


Figure 2: A wireframe of RoutineAid used in the formative study. A key design concept is that the building (with the main character) develops as routine tasks are completed.

3 FORMATIVE STUDY

To understand the individual challenges and the social and health issues that interfere with daily routine regulation and to identify the key design goals of the routine management system, we conducted semi-structured interviews with the following stakeholders: autism professionals, parents of individuals with autism, and individuals with autism.

3.1 Study Procedure

We recruited a total of 15 participants – five autism professionals, five parents of individuals with autism, and five individuals with autism (Table 1). From autistic professionals and parents of individuals with autism, we wanted to understand autistic individuals' perception and management status of their routines from various angles. From individuals with autism, we asked about their routine-related experiences and challenges and what factors and directions they expected from the functional or design aspects of the app. The inclusion criteria for individuals with autism included (1) age over 18, (2) presence of autism diagnosed by a qualified medical professional, and (3) capacity to understand the main concept of *RoutineAid* and complete interviews without any assistance. We employed a wireframe of the initial version of *RoutineAid*, which introduces the basic concept that the character and the village gradually grow up as certain routine tasks are performed (Figure 2). Participants joined one-to-one interviews after going through the prototype, and the average duration of the interview was 42 minutes. We encouraged them to ask any questions related to the wireframe, making sure that they conceptually understood how *RoutineAid* worked. The interview questionnaires mainly focused on topics pertaining to the changes in daily routines due to COVID-19 and preferences and challenges for the wireframe of *RoutineAid*. Two authors of this paper independently coded interview transcripts, repeatedly discussing the coding results to categorize themes until the coders reached a consensus. The inter-coder reliability was verified by the Cohen's Kappa measurement. The scores for each category were higher than 0.76 (max: 0.93, avg: 0.87), indicating that the inter-coder reliability lies between "substantial" and "perfect" [41]. For the formative study, the participants signed an informed consent form. This study was approved by the Institutional Review Board (IRB) at the authors' institution (B-2202-736-302).

3.2 Study Results and Design Goals

Drawing on the thematic analysis of the interview and feedback from autism stakeholders, we identified key ideas to support daily routine management for individuals with autism effectively. We mapped each challenge with the corresponding "design goal" as follows.

3.2.1 Anxiety amplified due to a broken routine. The interviewees reported that the care center- or school-oriented life patterns of the individuals with autism were disrupted because of COVID-19. In addition, the interviewees reported that it took a lot of work to comprehensively manage the daily routines with only the center's or the school's remote programs. *"I [a mother of an individual with autism] am trying to help him [the mother's child with autism] form a healthy daily routine as much as possible. But I can't watch him and care [for him] all day long. [...] Now, he can't do any type of physical*

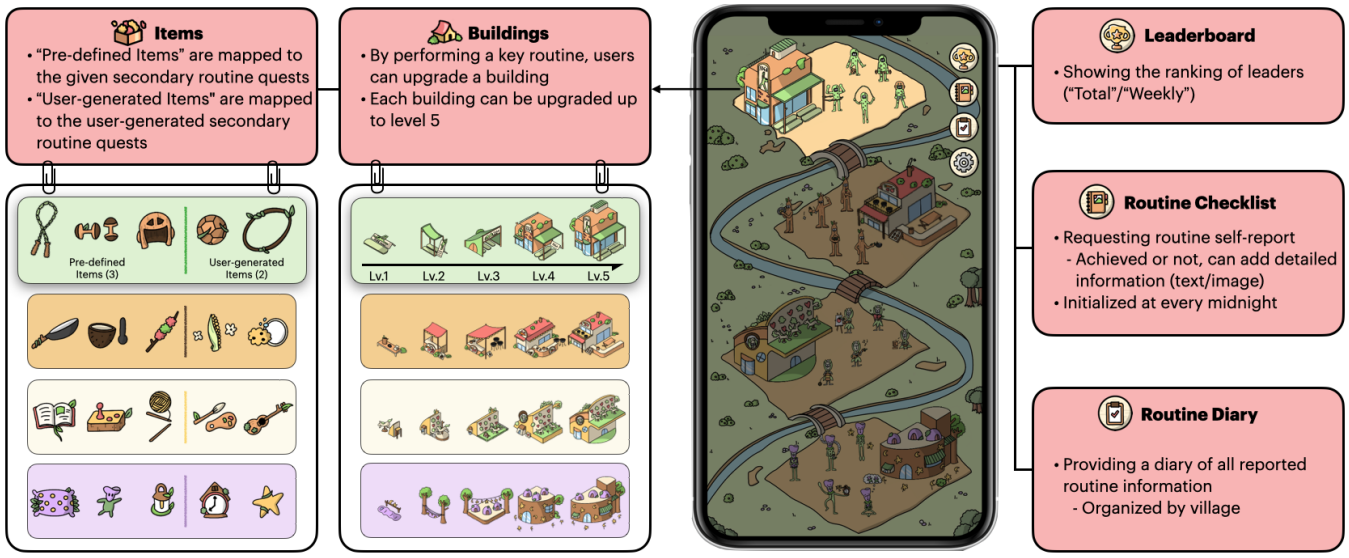


Figure 3: Overview of RoutineAid. Users can access each village by tapping each area. RoutineAid supports four key routine quests (mapped to buildings, one per village) and a total of 12 secondary daily routine quests (mapped to "pre-defined items," three per village). Users can add up to two user-generated secondary routine quests by themselves (mapped to "user-generated items," up to two per village). The overall introduction of the app is available at: https://youtu.be/Eln3-DpU0pA.

activities that he used to do at the minimum at the care center. Well, now he doesn't have any choice but needs to do it on his own, but really, he doesn't know what to do first and how to do [it]" (FP2). An autism professional brought up the need for more accessible tools, such as mobile apps, to independently manage the daily routines. *"I think developing this kind of app [RoutineAid] is very important. It's [...] not only [because of] COVID-19, but it doesn't really matter for those who [can afford interventions] when they have similar problems later on. Honestly, there are a lot of things that can be solved if you spend more money. [...] You can hire a physical activity instructor to regularly run a one-on-one program. But there are a lot more people who can't afford it. For those people, we really need these kinds of apps" (FA3).*

Especially for the design of support for routine management, we noted that the configuration of the "visual narrative" based app showed a positive impact on increasing user engagement. *"They're visual learners, so I think routine quests can be delivered better in this way. The word 'routine' can make them feel like something always organized all the time and quite solemn. I think it'll minimize those feelings if the design of the app will reflect well their preferences for visual-oriented and engaging designs" (FA5).*

Based on these insights, we derived the following design goal.

- **DG1**: Provide opportunities to explore and plan appropriate life rhythms with visual narratives

3.2.2 Lack of comprehensive management and support for key daily routines. We confirmed that COVID-19 has disrupted the everyday lives of individuals with autism. Different types of subroutines were all related to each other and formed a type of routine chain. For example, eating and sleep routines were disrupted, as even minimal physical activity was largely reduced, which worsened aggressive behavior or inappropriate emotional expression (e.g., self-injurious behavior). To address this, the autism stakeholders mentioned the importance of the sustainable management of key daily routines. One autism professional insisted that *"Because of the short duration of [the operations of] outpatient clinics, we usually focus on prominent issues, such as severe emotional anxiety and aggressive behavior. However, the fundamental reason for these issues is that the core routines are broken. It's great to be able to manage this kind of support together because patients are usually neglected in this area" (FA1).* One parent of an individual with autism further mentioned that *"If they [individuals with autism] can repeatedly practice, and then record which routines they need to supplement, it's good for themselves and also good for parents because they can get important information about the treatment" (FP4).*

The individuals with autism noted that the continuous management of their key daily routines would be effective stepping stones for their independent living in the future. *"People like me [individuals with autism] should keep trying to maintain a balanced life on their own but we need some sort of support. I think an app like RoutineAid can help me face [that] moment in advance and practice" (FI3).* A father of an individual with autism also mentioned, *"I have nothing to worry about if I can take care of my son for the rest of his life, but I can't. So, it's much better to practice social independence as soon as possible in the basic part. I'll be very relieved if he can manage at least his basic daily routine" (FP5).*

Using these insights, we derived the second design goal.

- **DG2**: Provide opportunities to achieve sustainable key daily routine management

3.2.3 Difficulty in elaborating tasks to form healthy daily routines. As mentioned in Section 3.2.1, we found that individuals with autism tended to be unaware of the underlying problem with their disrupted routine or had difficulty in executing problem-solving. The autism professionals noted that individuals with autism need support in specifying tasks that need to be prioritized. *"Because they*

Challenge	Design Goal (DG)	Functionalities of RoutineAid
Anxiety amplified due to a broken routine	(DG1) Provide opportunities to explore and plan appropriate life rhythms with visual narratives	• Main screen (villages and items) • Routine checklist (Sec. 4.3.2)
Lack of comprehensive management and support for key daily routines	(DG2) Provide opportunities to achieve sustainable key daily routine management	• Main screen (villages and items) • Routine diary (Sec. 4.3.3) • Leaderboard (Sec. 4.3.4)
Difficulty in elaborating tasks to form healthy daily routines	(DG3) Provide opportunities to explore actionable daily routine planning	• 4 key routine quests - mapped with villages (Sec. 4.3.1) • 12 pre-defined secondary routine quests - mapped with items (Sec. 4.3.1) • User-generated secondary routine quests - can add up to 8 routine quests (Sec. 4.3.1)

Table 2: Transition into the design goals and design elements of RoutineAid from the challenges of daily routine management.

[individuals with autism] often lack execution capabilities, they sometimes find it difficult to plan or figure out what to do first" (FA2). In addition, we confirmed that routine-related concerns of individuals with autism vary, and therefore, some degree of support for personalizing routines in an elaborate manner is needed to mitigate the deterioration and regression of those concerns. *"For my child, he was aware of the issue he is facing, but it was difficult for him to organize a specific and clear solution step by step. [...] He has a sleep disorder due to caffeine intake in the late evening. He seemed to have difficulty setting specific caffeine intake restrictions on his own. I personally think it would be nice if he set specific goals for the facing issues and share the progress with me" (FP1).*

Interestingly, although the individuals with autism also required elaborate and achievable guidelines for sustainable *RoutineAid* use, they had a different perspective from the parents regarding how to form self-directed routine management habits. One of the individuals with autism noted that *"It would be nice if autism professionals could help me set achievable goals and encourage me to improve my routine and impulsive behaviors on my own. But, I don't want them [autism professionals] to share my status with my parents. [...] When my parents intervene or point out my routine, they are just nagging. So, I always become over-recognized and emotionally responsive" (FI1).* This highlights an important design consideration for providing individuals with autism with the experience and feeling that they manage their routine quests on their own.

As a result, we set the last design goal as follows.

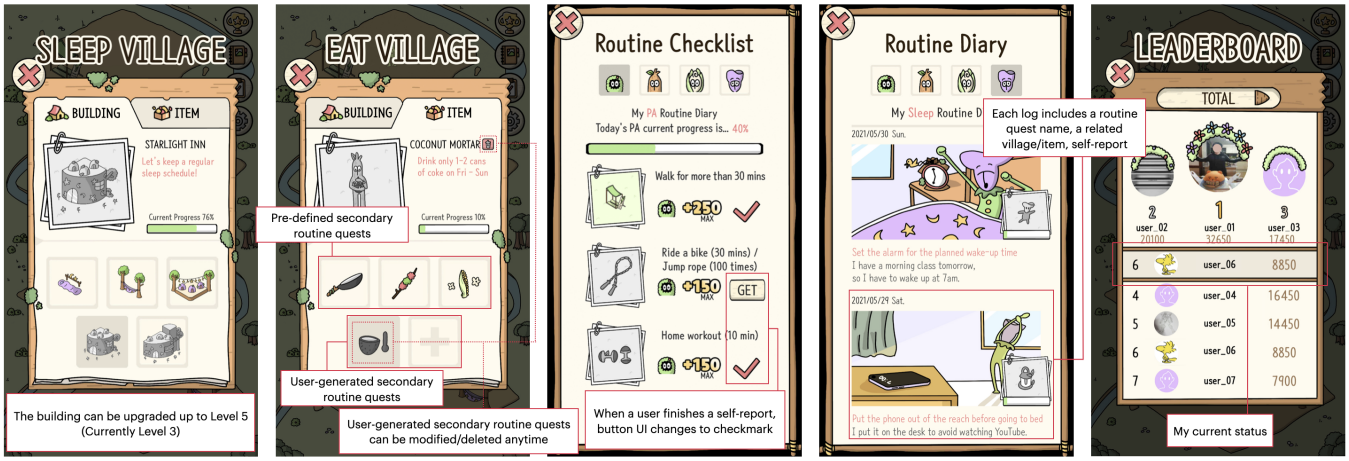
- **DG3**: Provide opportunities to explore actionable daily routine planning

4 ROUTINEAID SYSTEM DESIGN

Based on our design goals, we developed a gamified app, *RoutineAid*, for the daily routine management of individuals with autism (Figure 3). We redesigned the app until it reflected the results identified in each iteration, similar to the process proposed by the Reflective Agile Iterative Design (RAID) approach [28]. In each iteration, the autism stakeholders who participated in the formative study were involved. The final prototype of *RoutineAid* allows users to earn game points, upgrade four buildings, and collect items as they complete routine quests. These features are mapped on the main page, which shows the overall routine status and four main interfaces: (1) *buildings/items*, (2) *routine checklist*, (3) *routine diary*, and (4) *leaderboard* (Figure 4). *RoutineAid* encourages the users to visit the *routine checklist* every day and displays logs of the routine records in the *routine diary*. The main screen visually shows the user's comprehensive routine management status. Buildings and items visually provide the users with the types of routine quests assigned to each building or item. Table 2 summarizes how the identified challenges and design goals from the formative study were translated into the main functionalities of *RoutineAid*.

4.1 Selection criteria for the four representative routine components

We selected key routines from the important routine components identified in previous studies and from our iterative discussions with the autism stakeholders who participated in our formative study. Previous studies have found that a healthy daily routine must include regular "physical activity" and regular "intake of balanced food" [60]. Regular physical activity within a healthy routine helps improve cognitive ability and executive function [12] and has a positive effect on the overall quality of "sleep" and "mental health" [40]. Moreover, an unbalanced diet exacerbates the feeling of anxiety or the risk of depression [19], and insufficient or irregular sleep adversely affects mental and emotional health [3]. These four routine components are interconnected, and any deficiency in one element could result in a chain imbalance. Many hospitals and welfare centers have also emphasized the importance of a structured daily life for individuals with autism through the COVID-19 guidelines [11, 29]. In the pandemic, stress resilience is as important as body immunity [56]. The minimum social opportunities for individuals with autism have become even more scarce and there are limited ways for them to express their emotions. Unlike other routine components (e.g., physical activity, eating, sleeping) where parents/guardians can visually identify changes, psychological conditions are accompanied by risks that are known only through



(a) Buildings (b) Items (c) Routine Checklist (d) Routine Diary (e) Leaderboard

Figure 4: Screenshots of RoutineAid. In (a) and (b), each building and item are presented with the corresponding image and progress bar. In (c), the users move to four routine components by tapping the icon above. In (d), the users can upload their own images related to each routine quest. In (e), the users can check their progress through a leaderboard.

unexpected behaviors that arise from deterioration (e.g., self-harm, running away from home). We reaffirmed the importance of these four routine components, and, with the autism stakeholders who participated in the formative study, selected and set them as villages of *RoutineAid*: (1) physical activity village, (2) eat village, (3) mindfulness village, (4) sleep village.

4.2 Design Process of RoutineAid

4.2.1 Determining routine quests. We iteratively discussed with the autism stakeholders who participated in the formative study, and finalized a total of 16 routine quests (four routine quests per main component). For the finalized routine quests, we provided explanations in as much detail as possible (i.e., walk for more than 30 minutes), considering that individuals with autism commonly have difficulty in elaborating tasks for problem-solving (Section 3.2.3). Each main component has the *key routine quest*, and the user can upgrade a "building" when the key routine quest is achieved. The remaining routine quests were set as the secondary goals (namely, *secondary routine quests*) and mapped with the "items" presented with the character on the main screen. Table 3 summarizes the routine quests.

4.2.2 Building a game narrative of RoutineAid. *RoutineAid* was designed based on an embedded game narrative [61]. Unlike traditional narratives, the game narrative has interactivity that allows users to communicate with game stories, a fictional universe, and a nonlinear characteristic (the structure of the narrative is not fixed) [53]. Thus, through the game narrative, users can find meaning in the game, have a stronger connection to the game, and become motivated to play the game continuously [27].

RoutineAid was designed to have consistent narratives and to encourage users to establish a fictional universe so that they can be more engaged and learn better what they did while using the app. We identified the preferences for collecting characters and items from the individuals with autism in an iterative redesign process with autism stakeholders. To reflect these preferences, we decided to refer to the movie, "Inside out" for the design of the story. "Inside Out" tells the story of five human emotions (joy, sadness, fear, disgust, and anger). The characters in the movie become human and take on the expressions and behaviors related to each emotion. Similarly, in *RoutineAid*, each village is represented by a building and a specific character, and in each village, there are five types of items which can be acquired by completing the secondary routine quests (three pre-defined quests and two user-generated quests). Each character has own name and its metaphor: (1) Shruby - A shrub with persistent woody stems, (2) Sequiet - Sequoia sempervirens which is the Earth's tallest tree, (3) Hoplie - May lily, which means "regained happiness," and (4) Yawnee - Morning glory that usually starts to fade a few hours before sunset and unfurls into full bloom in the early morning. We introduced the design of these four characters to individuals with autism in the formative study and received positive feedback on the characters.

On the main screen of *RoutineAid*, the obtained items are displayed as different animated actions of characters (Figure 3 shows five characters per village). Based on a user's achievement of the routine quests, the user can upgrade the buildings and acquire the items. We expected that such narrative components will encourage users to use and interact with the app with lightly greater intimacy.

4.3 Key Functionalities of RoutineAid

4.3.1 Buildings and items. As shown in Table 3, *RoutineAid* consists of four villages. Each village has the key routine and five secondary routine quests. Three secondary routines are associated with predefined tasks, and two secondary routines can be defined by the user. As shown in Figure 4 (a) and (b), users can check the progress of their achievement for the buildings and the items. When the progress reaches 100%, the building or the item with the corresponding character will be presented on the main screen, along with vibrant visual and sound effects. To encourage participation, *RoutineAid* sends a reminder notification twice a day (at 2 p.m. and 7 p.m., that is, after lunch and dinner), and sends the users a final reminder

Village Character (name of village)	Routine Type	Game Element	Routine Quest Description
 Shruby (Physical Activity)	Key	PA village	Walk for more than 30 minutes
	Secondary	PA item 1	Ride a bike for 30 minutes or jump rope 100 times
		PA item 2	10-minute home workout
		PA item 3	Run outdoors for five minutes
		PA item(s) 4-5	User-generated routine quest(s)
 Sequiet (Eat)	Key	Eat village	Regular intake of meals
	Secondary	Eat item 1	Calculate meal calories
		Eat item 2	Calculate snack calories
		Eat item 3	Clean up the tableware
		Eat item(s) 4-5	User-generated routine quest(s)
 Hoplie (Mindfulness)	Key	Mindfulness village	Write a mind diary
	Secondary	Mindfulness item 1	Do a simple household chore
		Mindfulness item 2	Obey the screen time limit on the app usage plan
		Mindfulness item 3	Thorough personal hygiene (e.g., wearing a mask)
		Mindfulness item(s) 4-5	User-generated routine quest(s)
 Yawnee (Sleep)	Key	Sleep village	Keep a regular sleep schedule
	Secondary	Sleep item 1	Plan your day for tomorrow
		Sleep item 2	Set the alarm for the planned wake-up time
		Sleep item 3	Put the phone out of reach before going to bed
		Sleep item(s) 4-5	User-generated routine quest(s)

Table 3: Four characters, four key routine quests, and 12-20 secondary routine quests ("Key: key routine quests," "Secondary: secondary routine quests," "PA: Physical activity"). Each village has the key routine quest. When users complete the key routine quest, they can upgrade a building. Each village has five secondary routine quests. Users can earn the items when they complete the secondary routine quest. Three items (items 1-3) are associated with the pre-defined routine quests by the system, and the rest are associated with the quests that the user defines (Figure 3 for the items).

once a day (at 9 p.m., to give the users enough time to report before midnight) to collect their *routine checklist* responses.

4.3.2 Routine checklist. As shown in Figure 4 (c), users can check the completion status of routine quests through the *routine checklist* and move to other villages by tapping the character icon at the top. After completing each of the routine quests, the user can receive game points by pressing the "GET" button. A prompt message will pop up, and the user will be asked to complete two additional steps (Figure 5). Each step has a simple question (e.g., in the case of the key routine quest of the physical activity village, Q1: *Did you exercise at a similar or higher intensity to walking?*, Q2: *Did you keep walking for more than 30 minutes?*). We applied this two-step process to prevent misreporting and to enable the users to naturally verify whether a routine quest was performed correctly. Furthermore, users can earn extra game points if they add text or an image to provide additional information on the performed routine quest (Figure 5). The status of the routine quests is initialized at midnight, as the autism stakeholders suggested.

4.3.3 Routine diary. *RoutineAid* provides *routine checklist* responses through a *routine diary* (Figure 4 (d)). Users can monitor their routine logs at any time in counter-chronological order. *Routine diary* shows the visualized status of the corresponding building or item for each routine quest through the progress bar. In addition, text/image information for each routine submitted to *routine checklist* is presented in real-time. For quests that do not have submitted images, the default images are shown.

4.3.4 Scoring and leaderboard. Users will earn 200 and 100 points for completing the key routine and the secondary routine, respectively. Submitting text or an image about their experience of the quest through a *routine checklist* will give them an additional 50 points. The leaderboard has two time periods (i.e., Total and Weekly) for displaying the top seven users and gives more recognition to the top three by displaying a larger user profile photo and additional decorations for each of them (Figure 4 (e)).

5 FIELD STUDY METHODOLOGY

To examine how users' perception and management of their routine would be affected by their use of *RoutineAid*, we conducted a field study for two months. We then conducted interviews with two

Figure 5: An example of Routine Checklist responses. A user answers two questions (left and middle) and optionally submits additional information via text or an image for each routine quest (right).

secondary autism stakeholders to acquire their insights and advice on the identified findings.

5.1 Participants

We recruited 12 individuals with autism by distributing flyers to several autism-related organizations, clinics, and companies that hire autistic people and posting a recruitment notice on an online autism community website. As stated earlier in Section 3.1, our inclusion criteria for individuals with autism were: (1) age over 18, (2) presence of autism diagnosed by a qualified medical professional, and (3) capacity to understand the purpose of our field study and complete sessions without any assistance. We set the lower age limit to 18 based on the autism stakeholders' feedback, considering young adults need routine management more. Before the two-month field study orientation, two individuals with autism dropped out of the study due to personal mental health issues, and all their demographic data were immediately discarded. Of the 10 participants who remained, eight were male, and their ages ranged between 18 and 35 (Mean = 24). We measured the Autism Spectrum Quotient (AQ), which is a diagnostic questionnaire to measure autistic traits in an individual by one's self-assessment [7]. The AQ scores ranged from 33 to 42 (Mean = 38.13). Previous studies have indicated that a threshold score of 26 or higher exhibits the best screening characteristics [59].

All the 10 participants used *RoutineAid* for two months and joined the orientation and two review sessions under the same experimental protocol. We denote the participant quotes using "P-X" that refers to "Participant-Participant Number X" (e.g., "P-1" means "Participant 1"). For the two secondary autism stakeholders in Section 5.2.3, we denote their quotes using "S-X" that refers to "Stakeholder-Stakeholder Number X."

After the study, we gathered additional opinions on our study findings from two secondary autism stakeholders. The stakeholders have 15+ and 20+ years of experience as a psychiatrist and a behavior therapist for individuals with autism. With the insights from the study, we expected to not only examine the design requirements that we identified and applied to *RoutineAid* but also improve *RoutineAid* to be used by more individuals with autism.

5.2 Study Procedure

During the two-month study, the participants used *RoutineAid* and joined in three one-to-one, face-to-face sessions (one pre-study orientation session and two review sessions) with the researchers (the two authors of this paper). One participant was accompanied by his mother in each session due to psychological instability (P-2). The average duration of each interview was 43 minutes. In each session, we obtained their consent for the study and informed them that any content of the recording could be deleted if they wanted to, and the collected data could be disclosed to autism stakeholders in an anonymized form. During the interviews, we asked open-ended questions (Sections 5.2.1 and 5.2.2) on the feasibility of daily routine management and the overall user experience with *RoutineAid*. To analyze the interview transcripts, the two authors of this paper independently coded the results and compared them, identified recurring themes, and resolved any conflicts on the themes between them through iterative discussions. The scores for each category were higher than 0.71 (max: 0.86, avg: 0.79) through the Cohen's Kappa measurement [41]. The average duration of each interview to gather opinions from each of the secondary autism stakeholders was 63 minutes. This study was also approved by IRB at the authors' institution (B-2202-736-302).

5.2.1 Pre-study introductory session. In the pre-study introductory session, we introduced the purpose and process of the study. We notified the participants that they would receive $50 regardless of the progress of their routine quests, if they used *RoutineAid* for at least two months. Before starting the pre-study introductory session, the participants were asked to complete an online survey (Google Form[1]) that asked about (1) changes that they experienced

[1]https://www.google.com/forms/about/

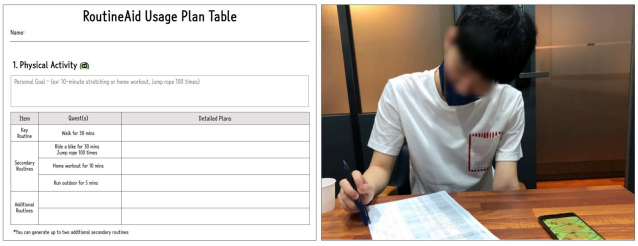


Figure 6: RoutineAid usage plan table (left) and a picture of a participant filling out the table (right). The usage plan table consists of four pages (one page per village). The participants were asked to set the goals for the four key routine components and strategies for each routine quest.

in their daily routine status due to COVID-19, (2) daily routine areas that they wanted to improve, and (3) the Autism Spectrum Quotient (AQ). Based on the survey responses, we first discussed the status of their routine management during COVID-19. We then identified their difficulties in managing daily routines and what routine areas they wanted to explore/improve through the study. The participants downloaded either an iOS or an Android version through a QR code, depending on which smartphone device they have. We explained the interfaces and reward processes of the app using the paper guidelines. We also asked the participants to fill out the app usage plan table (Figure 6). For P-2 who expressed difficulty in performing the pre-defined routine quest ("run outdoors for five minutes"), the researchers helped him add the user-generated secondary routine quest ("Go to the physical therapy center 3 times a week").

By doing so, the participants specified how to perform each routine quest or timeline (e.g., wake-up/sleep time, meal time, and the number of meal times a day). They used the app for two days to familiarize themselves before starting a two-month field study.

5.2.2 Review sessions. Two review sessions took place in the middle of and after the study. We conducted interviews to gather the participants' feedback on *RoutineAid* and changes in their daily routine management and perception. We also reviewed their app usage status. First, we discussed with them the earned game points and rankings displayed on their leaderboard. We asked them about their strategies to achieve their current ranking and what motivated them to use the app. Next, we identified the changes in the main screen of *RoutineAid*. We asked whether the participants had preferred design elements and how visual changes and upgrades/acquisitions of buildings/items helped them manage their daily routines. Then, we reviewed their routine diary by discussing their self-reports on their routine quests. In the final session, we asked them to share their thoughts and experiences on the following topics: (1) changes in their daily routines after using *RoutineAid*, (2) routine components and why they accomplished/did not accomplish, (3) components that have/have not been helpful, and (4) lessons learned in terms of daily routine management.

5.2.3 Opinions of the secondary autism stakeholders. With the two secondary autism stakeholders, we reviewed the app usage logs of the participants and collected the stakeholders' feedback on the interview responses, specifically focusing on the following aspects: (1) How are the findings associated with the characteristics of the participants? (2) What were the difficulties experienced by the participants in the use of *RoutineAid*? (3) What appropriate interventions can we provide to help individuals with autism engage in routine management? and (4) How can *RoutineAid* be used in COVID-19 and any other clinical environment? The purpose of the interviews with the two stakeholders was not to evaluate the participants' perception or use of *RoutineAid*, but to understand and corroborate it from more diverse angles. The participants' demographic information was not provided to the stakeholders, and the stakeholders had no contact with any institution or hospital related to the participants.

6 RESULTS

6.1 Establishing Concrete Daily Routines through Micro-planning

6.1.1 Comprehensive self-awareness supported by self-reporting. The participants reported that they have established a baseline for healthy routine formation through the key and secondary routine quests of *RoutineAid* (Table 3). *"Although I knew roughly the factors that I needed for a healthy life, [...] recently, I didn't go to the [welfare] center, so I couldn't figure out what to do to fulfill those factors on my own" (P-7).* P-3 further added that *"I often feel like I'm wasting my time without any plans, so I sometimes make a list of future plans vaguely on my cell phone. But it's really hard to carry out. [...] I think it's good that the app suggests directions in this respect."* They also mentioned that the sessions with researchers on autism improved their self-awareness by realizing their challenges against a healthy daily routine and obtaining suggestions for supplementation. *"It was nice to talk about my daily routines periodically. Especially, he [a researcher on autism] reviewed all of my self-reports with me. So I could acknowledge what I needed to form a healthy routine suitable for me. Personally, RoutineAid [motivated me] to decrease [my] sedentary time" (P-2).* P-2's mother who accompanied him to each session added that *"My son usually did not want to go to the physical therapy center. However, while participating in this study, he started to prepare for going to the physical therapy center [...] before I made him be ready, and he tried to do the therapeutic exercises more diligently."*

We found that, through self-reports on the given routine quests in *RoutineAid*'s routine diary, the participants experienced opportunities for data-driven exploration of routine components that they had overlooked before. *"I think leaving daily records of all the components that make up my day really helps me a lot in looking back on today and planning for tomorrow" (P-9).* P-6 added that *"I swear, I would have given up after doing it for a while. But I had to keep writing here every day, and it shows how much I did yesterday, so I've tried to achieve my minimum goal in my mind."*

It was quite impressive to see that the participants actively employed self-reports of each routine to observe their daily routines (Figure 7 (a)). They responded to self-reports of routine quests 781 times on average for two months (min = 492, max = 1,118) and 13.01 times on average per day (min = 8.2, max = 18.63). The secondary autism stakeholders commented that the detailed guidance for goal-setting and self-reporting provided in the introductory session worked well and highlighted that such a process was necessary to help the participants have a better understanding of their daily routine patterns and added some suggestions. *"I think it will*

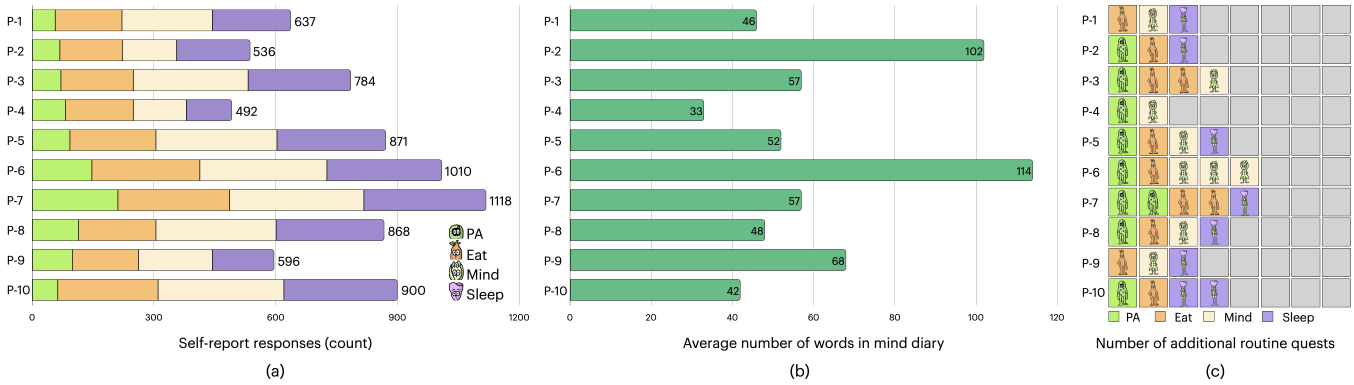


Figure 7: Quantitative analysis results in terms of micro-planning strategies. In (c), the gray slots mean the number of remaining user-generated secondary routine quests.

be difficult for individuals with autism to set goals and keep trying to form healthy routines on their own. However, when they realize what needs improvement through discussions with the researcher, they will at least start managing it. I think this app can be a good trigger for routine management as long as there is regular guidance by an autism professional" (S-2). She further mentioned that the process of reviewing self-reports together and checking the goals using *RoutineAid* would have helped micro-planning the goals to be achievable. *"The app already supports micro-planning, but [...] to further enhance their achievement, autism professionals need to make it achievable. For example, if it is difficult for an autistic individual to walk for 30 minutes from the beginning, researchers can suggest gradually increasing it from 5 to 10 minutes, from 2 to 3 times a week."*

6.1.2 Use of a mind diary to organize thoughts and express personal feelings. As shown in Figure 7 (b), the participants engaged in writing a "mind diary" (82.30%; mean: 50.20 times), which is the key routine quest of Mindfulness Village (Table 3), with an average of 61.9 words per diary. The participants mainly used the mind diary as a tool for expressing and reflecting on their emotions and experiences. *"I think I get angry more often while playing games these days. So I often fight with my sister. I don't write down special stories in my mind diary. Mostly, [I] write down what I did today, how many times I got angry, and why. [...] seems like the number of times I got angry decreased by 30%" (P-6).* Another participant also mentioned that *"I have a lot of thoughts recently. But my parents keep giving me solutions, so I don't want to share my thoughts with them. [...] I feel more comfortable in improving my mood and prioritizing problems, fears, and concerns I am having by writing in [mind diary]. [By tracking] my self-talk day to day, I can often identify negative thoughts around me earlier. It was quite helpful to me" (P-9).*

In addition, the participants responded that they were able to better understand and manage their stress and felt better when writing down something in the mind diary. For example, P-1 thought deeply about his tantrums or meltdowns, and figured out a better way to cope with them. *"It was good to know exactly what the trigger of my tantrum was and what makes me happy, and when [...] a bad memory suddenly popped into my head, I tried to do many things to handle it. This time, I was whistling while writing some favorite numbers [all of the past scores from a favorite music competition TV program] on the board, and I found it really worked."* P-3 also wrote down concerns about what would happen in the near future, such as the social stimulus that would happen again after COVID-19. *"I wrote it in my mind diary because I was suddenly depressed thinking that I would have to go back to the dorm one day. The dorm is a nightmare. I desperately need a private space. [...] I'm already worried."*

Meanwhile, two autistic participants (P-6, P-8) felt negative emotions when writing in the mind diary. *"One day, I suddenly remembered that I was bullied in school 10 years ago while writing in my mind diary. This memory kept coming to my mind for a few minutes and made me angry. I think I showed a weird behavior to forget those memories" (P-6).* The secondary autism stakeholder commented that individuals with autism have a tendency to be more deeply immersed in their negative emotions than in their positive ones, and suggested a possible way to manage such a case. *"The method I actually do in an outpatient clinic may be helpful in coping with this situation. For instance, users can check their emotional temperature from 0 to 100 degrees while recording their emotional status (0: the least negative emotion, 100: the most negative emotion). If the temperature is over 60 degrees, we could recommend that users stop this routine quest and suggest alternative tasks" (S-1).* Another stakeholder mentioned that individuals with autism could focus more on expressing negative emotions because they have a relatively limited vocabulary for expressing positive emotions. The stakeholder suggested that *RoutineAid* can be designed to encourage autistic individuals to use positive words when explaining negative feelings. *"[...] I think it would be good to ask them to write on their mind diary using positive words or to specifically present them in a way like 'Let's use these words [examples of positive words]!' for the mind diary" (S-2).*

6.1.3 Strategic use of the user-generated secondary routine quests. In addition to the pre-defined secondary routine quests, the participants actively utilized user-generated secondary routine quests, which gave them more flexibility in managing their routines (Figure 7 (c)). They added an average of 3.7 secondary routine quests (min = 2, max = 5). We found that they used those quests to either set their own regular activities or cope with new behavioral goals (e.g., having a cup of mocha frappe only three times a week). Table 4 summarizes the user-generated secondary routine quests divided into two types: (1) usual routine and (2) new behavioral goal.

P-X	Type	Routine Quest	Reason for Adding
P-1	Usual	**Eat 2 blocks of tofu a day**	Enjoys soft foods since childhood because of his sensory issues. Tofu is his favorite soft food.
	Usual	**Go to music academy except on Mondays**	Enjoys listening to music and playing drums.
	New	Turn off the lights when going to bed	Usually falls asleep all of a sudden when the lights are on in the room.
P-2	Usual	**Go to the physical therapy center 3 times a week**	Being treated for a fall. He wanted to make up for missed scores, which can be obtained from the given high-intensity physical activity.
	New	**Drink mocha frappe only 3 times a week**	Usually drinks a cup of mocha frappe at the cafe every day.
	New	Measure total sleep time	The key sleep routine quest was not performed frequently due to his sleep disorders. Added to compensate for missed scores and see how much sleep he gets on average.
P-3	New	**Climb stairs twice a day to the 10th floor**	Lives on the 10th floor and added to use the stairs when coming back home.
	New	**Eat a hamburger only twice a week**	Eats junk food 4-5 times a week on average. Added to eat less.
	New	Avoid eating snacks when taking classes	Cannot control himself from eating too many snacks during lectures.
	New	Write about overindulgence moments	Usually easily immerses in political issues and becomes overly furious.
P-4	New	Sit upright at the desk during classes	The behavior that he recognized as a bad habit. Added to break it.
	Usual	Analyze the specs of vehicles in depth	Deeply interested in vehicles. Added to upload the specs and a photo of the car he analyzed.
P-5	Usual	**Commute standing on the subway for 12 mins**	Pre-existing routine recognized as minimal physical activity.
	New	Adjust the amount of my meals using a mess tray	Tends to be binge-eat. Added to practice eating the proper amount of meals.
	Usual	**Take my psychiatric medication pills after dinner**	Pre-existing evening ritual. Added because he sometimes forgets.
	Usual	**Listen to ASMR "Just Talking" to fall asleep**	Has a sleep disorder. This is his own way of sleeping relatively easily.
P-6	New	Practice a natural standing posture	Thinks his standing posture is unnatural. Added to practice good posture.
	New	Stop eating meals on the couch	Usually eats on the couch, and his mother nagged him to eat at the dining table.
	New	Measure daily Switch usage times	RoutineAid has reduced his smartphone usage time, but his Nintendo Switch usage time has increased instead.
	New	Write a reason for getting angry while playing games	Usually yells or gets angry while playing games. Added to try to improve this behavior.
	New	Write down about my comfortable moments	Thinks that every day is full of unpleasant things. Added to make a note when he felt comfortable.
P-7	New	Sit upright on a chair without lying face down when reading or writing something	Very reluctant to sit at a desk. Added to practice, since he is preparing to get a job.
	Usual	**Use the stairs at quitting time (6 p.m.)**	Reluctant to use the elevator because there are too many people when getting off work.
	New	**Eat 2 vegetable sides in every meal**	Does not like to eat vegetables, yet he knows the need. Added to try bit by bit.
	New	Write down why I throw up	Usually vomits while eating or right after. Added to write down the reason.
	Usual	Sleep while listening to new-age music	Pre-existing ritual. He enjoys listening to new-age music to avoid distracting thoughts.
P-8	New	Always sit upright during classes	Since he started attending college, he has become conscious of his posture. Added to maintain good posture at least during classes.
	Usual	Set the dinner table without any assistance	Prepares for independence from parents. Added to practice setting dinner by himself.
	Usual	**Do the vacuuming at 5 p.m. every day**	The robot vacuum cleaner finishes cleaning at 5 p.m. Obsessively wants to clean once more completely with a vacuum afterward.
	New	Avoid watching YouTube before going to bed	Has trouble stopping YouTube before going to bed. Added to avoid using electronic devices 30 minutes before going to bed.
P-9	New	Eat at the dining table without watching TV	Recognizes that he tends to binge-eat when watching TV. Added to manage together with other provided eating routine quests (e.g., calculate calories).
	New	Have a good listening attitude	His mind diary expressed his feeling that it was necessary to improve his listening attitude.
	Usual	Clean my room every morning	Pre-existing obsessive behavior.
P-10	Usual	**Go boxing every weekday (except on exam days)**	Pre-existing hobby. Prefers exercise that can be enjoyed alone.
	New	**Drink only 1-2 cans of coke on weekends**	Used to drink several cokes every day. He thought it would be difficult not to drink it completely, so he added it as a doable quest.
	Usual	Make my bed every morning	Pre-existing obsessive behavior. He mentioned it's annoying if he does not make his bed.
	Usual	Read picture books when I cannot fall asleep	Has a sleep disorder. When he cannot fall asleep, he reads picture-oriented books.

Table 4: The user-generated secondary routine quests. Participants showed a specific purpose for setting their user-generated secondary routine quests. Some of the quests (in bold text) were described in detail (e.g., when, where, how many). "Usual" and "New" indicate "Usual routine" and "New behavioral goal," respectively.

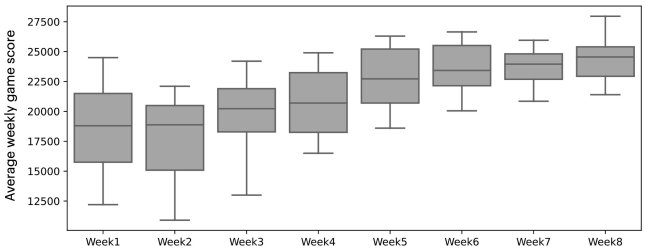


Figure 8: Box plots for the average weekly game score during the two-month field study.

First, the participants recorded their activities that could help them form healthy daily routines or enjoy their hobbies. *"I dust my blankets and clean my bedding every day. If I don't, it looks messy and bothers me all day" (P-10).* P-1 reported that he could go to bed only after performing his own rituals. *"I search 'ASMR Just Talking' on YouTube and fall asleep listening to it every day. Without it, my head is full of thoughts, so I couldn't sleep because I felt fear and anxiety. When I listen to music with lyrics, I get so immersed and go to bed too late. I need to listen to this [ASMR] so I can do RoutineAid's sleep routine quests" (P-5).* They wanted to effectively use *RoutineAid* by setting up additional actionable and creative routines.

Second, they attempted to achieve their new behavioral goals that they judged as obstacles to their healthy daily routine formation. *"I've been trying to cut back on my smartphone usage [Mindfulness item 2 in Table 3], and I've done it a little bit. Instead, I was more into Nintendo Switch. I think my average usage time has increased by about two hours a day, so I added this ['Measure daily Switch usage time' in Table 4] as my routine quest" (P-6).* P-2, who has sleep disorders caused by anxiety, noted that *"Sleep routine quests were the hardest part for me. I was used to going to bed at 3-4 a.m. So, the 'regular sleep' routine quest is the most difficult for me."* He also noted that users who have difficulty getting regular sleep would rather record total sleeping hours, and he set it as one of his secondary routine quests.

6.1.4 Establishing an elaborated routine for effective micro-planning. In Sections 6.1.1 and 6.1.3, we reported how participants performed the key and secondary routine quests. One interesting point is that the participants performed the routine quests according to their own rules and recorded what they performed very specifically. For example, P-10 noted that the goal should be detailed (e.g., 12 minutes of abdominal exercise), *"Were there any participants who didn't write down the time or number of exercise times? I wrote it down because I thought it was basic information that I had to convey."* P-4 and P-8 repeatedly submitted reports with exactly the same sentences (e.g., "*I didn't take off my mask and didn't order food at the PC room*," *"If I skip vacuuming at 5 p.m., it looks messy and makes me annoyed all night."*). In response to the question of why they submitted a completely identical record, P-4 mentioned, *"I think there is a compulsion to keep the grammar well and my own writing style, but I didn't mean to write the exact same things repeatedly."* Furthermore, when a certain word was outside the semantic category they defined, they showed a tendency not to record the quest; *"The routine quest name is 'clean up the tableware.' I only moved the tableware from the dining table. And, my house uses a dishwasher, which means I am not the one who cleaned up the tableware" (P-8).*

Especially for the user-generated secondary routine quests, the participants showed high motivation to specify and complete the tasks (Table 4 and Figure 7 (c)). *"I usually go to the gym on weekdays. But there is an exception on the exam day. So, when I set [a user-generated secondary routine quest] up, I wrote it down together" (P-10).* Interestingly, when reporting their progress, they did not add detailed reports on some of the user-generated secondary routine quests, but simply added "done" or "completed." We found that this was because the descriptions of those quests were already highly specified. P-5 mentioned, *"There was nothing to submit as additional text for [one of the user-generated secondary routine quests]. If I did it, then it was just what it was. [...] That's it."*

In summary, the participants performed micro-planning by submitting additional descriptions through self-reporting of given routine quests and elaborating explicit tasks when setting up the user-generated secondary routine quests. This shows the effectiveness of micro-blogging supported by *RoutineAid* in terms of creating a structure for and reflecting on the users' routine by themselves.

6.2 Maintaining Daily Routines through Celebratory Interactions

6.2.1 High playability through leaderboard. The participants were actively engaged in the ranking competition and were conscious of other users on the leaderboard. One of the indications was their participation, as illustrated in Figure 8 (average weekly game score). The participants showed consistent usage of *RoutineAid*. The average game score became higher throughout the study period, indicating that more routine quests were performed. The variance of the scores also gradually decreased over time, which indicates more consistent usage of *RoutineAid*. P-7 was also highly motivated to be ranked higher, thus tried out routines that he did not perform well or was reluctant to do at the start of the study. He noted that the experience of maintaining a high ranking was an opportunity that made him feel satisfied when he achieved the goal and reflected on himself. "*It's my first time in 22 years. Every time I'm used to being last in sports and exams. After winning the first place through RoutineAid, I gained confidence and it was a good opportunity to look back on myself. [...] I didn't care what time I slept, what time I ate, how much I exercised, but now I think I'll look back on it more frequently. [...] I also realized how lazy I was. Before I used this app, I used to wake up late at noon and have dinner at 10 p.m." (P-7).*

In addition, by virtue of their arithmetic and sharp observation skills, the participants showed a strong curiosity about how other participants managed their routines, asking, for example, "How many key and secondary routine quests did that user perform to accomplish [a specific score]?" Regarding this result, the autism stakeholders commented that the participants were obsessed with their rankings on the leaderboard and their focus on visible achievements unexpectedly led them to be interested in other users' achievements. *"[...] It may be because they think they should be in the first place. Previously, one of my clients had to take the first place in a certain arcade game, and he played it from morning to night. I think it's because individuals with autism tend to be obsessed with one particular thing. [...] In the end, even though this game gave him some reward, [...] the most simulating reward was the ranking on the leaderboard. I think that's why they cared about the rank more" (S-1).*

P-8 and P-10 even remembered the score trends of other users and easily inferred how many routines those users usually performed in a day. *"I check the leaderboard every morning. [User ID] always went up by 2,550 points or 2,400 points, but yesterday, he/she only went up by 1,400 points, so I was able to widen the gap" (P-10).* One participant specifically suggested a way to solve his curiosity about how other participants manage their routines. *"I wish this app had a feature for observing other participants' main screens. I want to check other users' village building levels and items. And, we can share each other's strategies. I can imagine roughly what they look like through the scores. [...] But that's not all" (P-3).* P-9 also proposed routine management through additional interactions with other users. *"I think it would be nice to have the functionality to compare or interact with the other participants. It would be good to do some routine quests together. And it's important to do it every day, so I think it'd be nice to have a time for attendance."*

6.2.2 Increased motivation for routine management through visual changes on the main screen. Among many UIs or functions of *RoutineAid*, the main screen which displays the status of the villages was mentioned by the participants as the most engaging page, receiving many positive user experiences. *"The main screen of RoutineAid shows how I'm spending every day, what I have achieved, and what I should do" (P-7).* In particular, most participants showed considerable interest in visual changes and updates of the main screen over time as they progressed more. *"From the second week of the study, I stopped on the main screen and checked the current status of the villages more often. And then I checked the progress bars because I was wondering what kind of items I will get and which building will be upgraded soon" (P-5).*

We found that some participants felt uncomfortable with the visual imbalance displayed on the main screen. For example, P-6 noted, *"After a couple of weeks of participating in this study, a clear difference began to be seen between the villages that developed well or those that did not. Such a visual imbalance on the main screen kept bothering me, so I wanted to make it more harmonious."* This finding was particularly frequent in the Physical Activity category, where the performance of routine quests was relatively low (Figure 7 (a)). Some participants made an additional effort to perform at least some of the given physical activity routine quests. *"I hate physical activity. So I usually don't move without a specific purpose. However, only the physical activity village seems so empty. So when I go to the shop, I at least try 'walk for more than 30 minutes' [the key routine quest of physical activity village]. [...] I wandered around the store for extra 7 minutes because it took around 23 minutes for the round trip" (P-8).* In addition, as shown in Table 4, a half of the participants (P-3, P-4, P-6, P-7, P-8) added the user-generated secondary routine quests that are relatively easy to perform at least to maintain a certain degree of villages' visual richness. *"For me, it is very difficult to obtain physical activity items. I know that moderate- and high-intensity exercise is good for my health, but I just don't want to perform those quests. So I added a body stretch routine to acquire at least one more physical activity item" (P-4).*

6.2.3 Positive impact of routine management with visual narrative. As we expected, the participants reported that *RoutineAid*'s visual narrative with buildings and items had a positive impact on the immersion and familiarity of gameplay. *"It was fun to connect the buildings and the items with the part of my day. I can easily check my everything [daily routines] from the story of the app. So it seemed easier to do the routine quest for me" (P-2). "The overall style of the app and the different way each cute character speaks when delivering the missions [routine quests] were like comic books. The design is quirky and lively. So I had less rejection" (P-5).* We also confirmed that the participants were very encouraged by the celebratory overlay on the main screen as rewards with vibrant visual effects and sounds. *"I was excited when I received a notification saying, 'Your reward has arrived.' I was looking forward to seeing some rainbow lights" (P-4).* The participants also used routine diary of *RoutineAid* by reflecting their daily routine with the visual narrative of the app. For instance, P-3 mentioned that *"The routine diary helped me look back my life patterns like a photo journal in my childhood. Also, I liked that the default images were cute too."*

All participants reported that the changes/updates of the villages made them feel the villages as emotional entities and motivated them to continue to manage their routine every day. *"The buildings and the characters with items were so cute, and I like the way the app conveys routine management to me. Once I got more items, I got attached to the app more. So, I tried to finish as many [quests] as I could" (P-4).* In addition, they reflected their personal preferences on the design of characters and buildings in managing daily routines. *"I'm a huge fan of 'I'm a Loner [a similar version of Man vs. Wild TV series].' That's why I like 'Bush-man' [the name of physical activity character] the most, and I wanted to collect all of items for 'Bush-man' " (P-7).* P-1 reported that he managed more villages resembling his preferred place; *"I liked Mindfulness village the most because the building reminds me of my favorite place. So, I tried to raise the level of that building faster than others."*

In summary, we found that the game narratives applied to *RoutineAid* were effective in that they stimulated the users' participation in managing their routine and helped them achieve considerable synchronization with their daily routines. The secondary autism stakeholders also commented that the visual reward of *RoutineAid* immediately rewarded the users enabled their continuous use of the app. *"These days, people who have lost their entire routines due to severe depression often visit. For those people, I usually give them homework to write on their calendars what they did today and how they felt. However, there is no visual compensation in this method, and it seems verbal compensation is insufficient" (S-1).* In addition, we confirmed that individuals with autism seem relatively more sensitive to inadequate visual compensation or excessive visual regression. A stakeholder mentioned that P-8 temporally experienced a visual downgrade of one of the buildings caused by a system failure, and pointed out that frequent visual downgrade bugs could lead to loss of motivation to use the app. *"Of course, it was temporary, but if this visual deterioration of the system was prolonged or excessive, the willingness to use a particular routine or app itself could be drastically reduced" (S-2).*

7 DISCUSSION AND DESIGN IMPLICATIONS

From the results of the two-month field study, we confirmed that the user requirements and design elements identified in the existing literature were well reflected in *RoutineAid*. In Section 2.1, we found that apps developed for individuals with autism do not

cover multiple key components that constitute one's overall routine (rather focus only on a single component) or make individuals with autism feel burdened in app use due to the app's excessive degree of freedom. Thus, we provided the elaborated routine quests in the app and experts' regular interventions (e.g., filling out the app usage plan table and setting up the app onboarding). As a result, the participants effectively performed routine exploration and micro-routine planning on their own (Section 6.1). In addition, the results in Section 6.1.4 reaffirmed the effectiveness of the gamification and visual narratives highlighted in Section 2.2. Below, we discuss the qualitative and quantitative aspects of *RoutineAid* and present design considerations that could provide researchers with future research guidance on system development for individuals with autism.

7.1 Providing Routine Quests Adaptive to a User's Context, Progress, and Preferences

Most of the existing apps for behavioral change have high degrees of freedom (i.e., from goal setting to reporting) [25, 36] or only provide additional information on a specific area (e.g., diet and nutrition), with less consideration for increasing the user's motivation [2, 57]. This may not be suitable for individuals with autism who have relatively insufficient executive functions and difficulty in systematizing tasks. To address this limitation, *RoutineAid* provides four routine components with specific routine quests and allows individuals with autism to self-monitor their routine status through visual support. Furthermore, through discussions with autism stakeholders, *RoutineAid* offers tasks that are essential and doable for healthy daily routines of individuals with autism as routine quests and provides the key daily routine frame. The participants reported that they could effectively monitor their daily routines through periodic reviews by planning and self-reporting (Section 6.1); however, they also showed difficulty performing when the required routine quests by *RoutineAid* were not executable under their stabilized life pattern. This was especially observed in the Sleep category. The participants who experienced sleep disorders had to obtain a minimum sleep time before performing sleep quests (e.g., sleep before midnight). Some participants expressed inconvenience with the fact that routine checklists are initialized every midnight, which is earlier than their average bedtime. Some of them created additional quests to manage their sleep schedule and earned some game points from the Sleep village as a workaround. In the same manner, the participants identified primary barriers to performing the proposed routine quests and set up user-generated secondary routine quests as actions to overcome obstacles (Table 4).

Such challenges may be mitigated by providing flexibility to the app in terms of quest creation, modification, and management. However, given that individuals with autism still need guidelines, it is still important to encourage users to complete the key routine quests suggested by the autism stakeholders for their development and routine management. To increase the system adaptability, routine quests can also be designed and provided considering user progress, preferences, and context. One possible design is subdividing the achievement criteria of the existing routine requests and allowing users to incrementally complete smaller requests, giving them partial scores. They can also work on a portion of a task and complete the remaining portion later. Although such adaptive approaches could increase the complexity of the system implementation, they could effectively mitigate user compliance issues in automated coaching and self-tracking systems [38] and increase user participation.

7.2 Balancing Self-directed Behaviors and Experts' Regular Interventions for Long-term Routines Management

We found that the individuals with autism showed difficulty in their initial use of features with high degrees of freedom, such as filling out the app usage plan table and setting up the app onboarding. However, once the process was successfully done with the researchers' intervention, the participants were able to conduct routine exploration on their own. With regular review sessions with autism experts, it appears that the participants have enough capability to successfully use the app. Therefore, while a mobile app should be designed for independent use, some steps need direct guidance and timely intervention by experts, offering customization of interventions that will work flexibly depending on users and their environment. This is an important design element that can help increase not only the likelihood of using a mobile system but also self-efficacy [6], encouraging individuals with autism to believe they can accomplish their desired outcomes.

To better support this design implication, *RoutineAid* can be revised to allow users to set routine quests in a more flexible fashion with an expert's guidance, depending on each user's physical or psychological causes. For example, P-2, who is unable to walk for a long time or run due to the medical issue, was guided by researchers to gradually perform physical activity routine quests (e.g., do therapeutic exercise in physical therapy center, ride an indoor cycle for 10 minutes). We speculated from his mother's comment that his sense of self-efficacy for physical activity improved (Section 6.1.1). Thus, if the user's existing pattern conflicts with a key routine quest, one design idea is to provide individuals with autism an opportunity to discuss with experts prior to performing routine management, which may also help the experts identify the problems that the individuals with autism confront and give them the most appropriate guidelines.

7.3 Leveraging Visual Elements of the Main Screen to Trigger Enhanced User Engagement

The participants frequently checked the overall routine status through the main screen, and expressed discomfort with the visual imbalance of the four villages (Section 6.2.2). This is related to the characteristics of the autism population preferred for visual reasoning processes [31]. The participants had difficulties in performing the given routine quests of Eat village, while wanting to balance the development of the villages for their psychological stability. To do this, some of them added a small, doable user-generated secondary routine quest (e.g., write down why I throw up). These findings show that *RoutineAid*'s main screen, which reflects DG 1 and 2 from the formative study, plays an important role in motivating the

participants to achieve healthy and balanced daily routine management. Therefore, when designing a system to manage routines of individuals with autism, it would be important to have them check their status with visualized effects as easily as possible. In addition, creating a user-generated secondary routine quest that gives additional visual rewards (item acquisition) was found to be a good direction for self-structuring healthy daily routines. Researchers on autism can leverage the visual sensitivity of individuals with autism to effectively guide them toward incrementally reaching the recommended level of routine management.

7.4 Beyond a Rank-focused Leaderboard: Sharing Information about Fellow Users' Progress and Strategies

During the field study, the participants continued to keep track of the scores and rankings on the leaderboard and actively participated in the competition. They also paid close attention to the scoring mechanisms (Section 6.2.1). These are mostly related to their outstanding arithmetic reasoning skills [14]. Although not all individuals with autism have exceptional arithmetic skills, they are generally more familiar with the handling of unique mnemonic strategies than of logical information [23]. These cognitive processes amplify the autistic participants' curiosity about the source of information displayed on the rank-based leaderboard. In other words, individuals with autism have a high affinity to the puzzle-solving aspects of the game score mechanism [34], which typically demand more systematic thinking. The participants also enjoyed inferring and imagining other participants' buildings and items although they were only able to access the leaderboard, not logs of participants' achievements. Therefore, when designing a system for individuals with autism, it will be worth considering providing additional information (e.g., the rationale behind the scores being calculated) about other users' participation and use history while preserving the users' privacy. This will increase app playability and engagement. For example, clicking on a user's ranking or score can show the trends in the earned scores for each village. It is expected that knowing about the participation and achievements of high-ranked users will motivate individuals with autism to actively and strategically use the app.

7.5 Visual Support Considering Loss Aversion

We confirmed that the visual support had a positive impact for individuals with autism on exploring their daily routines (Section 6.2.3). In particular, they were motivated to manage their routines through visually positive changes, such as the upgrade of buildings and the acquisition of items. However, some participants pointed out a possible gradual gap between poorly managed and well-managed routines if only positive visual support was provided. This may lead to imbalanced routine management, focusing more on routine types with positive rewards. Here, additional visual support can be considered through loss aversion. Loss aversion is a psychological theory that people are more sensitive to loss than gain [1]. In terms of game design, loss aversion is mainly used to induce continuous user participation through users' loss anxiety [17, 26]. In other words, when users do not accomplish their remaining game missions and use all the given chances, they are eager to play more to achieve those missions under the illusion that they are close to achieving them. This game design consideration may especially encourage individuals with autism to engage more because they tend to alter their decision-making strategies to avoid negative consequences [22]. Furthermore, given their preferences for visual reasoning [23], configuring design elements to show visual connectivity between each interface and reward can enhance immersive app use. In the same vein, potential users of *RoutineAid* may show a more balanced gameplay, increasing awareness to the possibility of losing rewards for already accomplished routine quests and become motivated to regain the rewards. As highlighted by the secondary autism stakeholders (Section 6.2.3), it is also important to control a degree of negative effects. For example, if a user neglects management in one of the four villages, *RoutineAid* can visually express adverse effects (e.g., warning message, slight change of the background color) on other villages in a reasonable manner. Excessive changes of visual effects may result in unexpected consequences, such as lowering the motivation of app use.

7.6 Possible Data Use in Clinical Settings and Privacy Concerns

We noticed the tension between the desires of caregivers and those of participants with regards to data sharing. The secondary autism stakeholders discussed the possibility of using data from *RoutineAid* use as additional information for effective diagnosis and treatment. On the other hand, participants wanted to be aware of the details of their data being collected (e.g., accessible data types and users) and exhibited a conservative stance on the utilization and access of their logs.

The secondary autism stakeholders in our study mentioned that the data recorded by the participants could be used for clinical and treatment purposes. They noted that some of the data, such as sleep time, amount of meals, are difficult to obtain or sometimes less reliable due to low compliance of regular recording. After the stakeholders looked into the logs of *RoutineAid*, they mentioned that those records seemed to be well obtained. The stakeholders further mentioned that the participants had honestly recorded their thoughts and emotions in their routine diary, so that the autism professionals can check the current emotional state and changes of the participants. A previous study with adolescents with autism reported that autistic users write personal thoughts they do not want to share with others on the self-report app [35]. This kind of information is hardly accessible to caregivers and therapists. As the participants engaged in *RoutineAid* use, many daily logs were generated and recorded, providing caregivers and therapists with an opportunity to objectively identify the current physical and mental conditions of individuals with autism. This again highlights the importance of identifying key design considerations for a specific user group and reflecting them on the design of the app.

In order to have *RoutineAid*'s data employed in clinical settings, privacy issues of personal data must be considered first. Individuals with autism disclose their personal information too easily or have difficulty in setting appropriate data disclosure ranges [37]. In our study, some participants were aware of possible privacy issues. They wanted to know more specifically about the permissions of the app. They expressed privacy concerns, such as personal

information leakage. Some of them specifically asked to what extent the information recorded on *RoutineAid* would be exposed to other users, how much information the system developer or researchers can access, which permissions should be granted, and details on the permissions when installing the app. As the individuals with autism showed significant concern and wanted to know how their information would be collected and used, it is worth considering such aspects (e.g., by providing them with enough details regarding the types of user data collected, the use of their data, the privacy safeguards) when developing a mobile app.

7.7 Limitations and Future Work

While our two-month field study presented many insights and potentials about supporting daily routines for individuals with autism, we acknowledge two limitations as follows.

First, although the sample size of our study was comparable to those of previous studies that had a similar study design and length (n = 5 [35], n = 9 [34]), the impact of *RoutineAid* may not be generalized. Similarly, although prior studies have estimated that males with autism are approximately four times more than females with autism [45], our study still lacks gender diversity (67% are males). Our field study primarily focused on validating key design rationales and elements to support the daily routines of individuals with autism. Although a two-month field study is somewhat sufficient to confirm the feasibility of *RoutineAid*, we are planning to assess the longer-term sustainability of *RoutineAid*, with a larger sample and more balanced gender diversity, as future work to investigate whether *RoutineAid* helps individuals with autism manage a structured and more balanced life in a longitudinal manner. Second, the individuals with autism recruited for the field study had sufficient cognitive function to understand our research and the main functionalities of *RoutineAid*. Our findings or insights may not be applicable to those who need more careful assistance from caregivers or with high-severity of autistic symptoms. Although the current version of *RoutineAid* is suitable for individuals with autism in a certain spectrum, the lessons learned from this study could be applicable to the development of a system for a wider spectrum of autistic individuals.

8 CONCLUSION

In this paper, we presented the challenges of individuals with autism in maintaining healthy routines and the design suggestions for apps for their independent and sustainable daily routine management. We conducted a formative study with autism stakeholders, through which we extracted design requirements for developing a gamified mobile app, *RoutineAid*. The results of our two-month field study highlighted that individuals with autism broke down their daily routines into micro plans, strategically managed their routine tasks, reflected on the routine reports, and exhibited high engagement through celebratory interactions. These results further suggested salient design implications, including user-adaptive routine quest provision, timely intervention by experts for sustainable routine management, enhanced user engagement via visual elements of the main screen, information-sharing support through a leaderboard, visual support via loss aversion, and possible data use in clinical settings and considering data privacy concerns. We hope our findings and suggestions in this study will provide researchers, designers, and developers insights on how to employ and design technology to help individuals with autism recover and improve their routine for their well-being.

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