Original Paper

# Design Requirements for a Smart Scoliosis Orthosis: User-Centered Design Approach

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## Abstract

**Background:** Adherence to orthosis use remains a key challenge in nonsurgical scoliosis treatment. Smart monitoring technologies can quantify wear time and skin-to-orthosis pressure to support treatment adherence. However, little is known about how Norwegian adolescents with scoliosis and their parents perceive such technologies or envision supportive monitoring systems integrated into daily life. Understanding user expectations is essential for developing user-centered digital monitoring solutions with features perceived as meaningful, acceptable, and supportive of treatment adherence.

**Objective:** This formative user requirements study aimed to identify user-driven design requirements for a future smart orthosis monitoring solution in Norway.

**Methods:** This study was conducted in 2 sequential phases between May and September 2025. In phase 1, a total of 7 adolescents aged 10 to 17 years with experience of orthosis treatment were purposively recruited through a patient organization and participated in 1 of 2 hybrid focus group discussions. Interested participants registered following a study invitation and were screened for eligibility by the research team. Data were analyzed using qualitative content analysis. In phase 2, a total of 23 adolescents with scoliosis and 30 parents or caregivers were registered for the patient organization's annual meeting. Anonymous Mentimeter polls and illustrative sketching activities were conducted during the workshop. As responses were collected anonymously, the number of responses varied across poll items and could not be linked to participant registration records. Poll responses were analyzed using descriptive statistics, whereas sketches were used as supportive material to aid the interpretation of participant perspectives and design preferences.

**Results:** Participants described orthosis management as being influenced by physical discomfort, heat, orthosis fit, activity restrictions, and the overall burden of treatment. Monitoring was perceived as valuable when it reduced uncertainty; supported self-management; and facilitated communication among adolescents, families, and clinicians. Temperature monitoring emerged as a consistently preferred functionality across the focus groups, workshop discussions, and polling responses. Participants also identified the monitoring of orthosis fit, activity, and wear time as important. Desired design features included automated feedback, progress visualization, reminders, data sharing with clinicians, and positive reinforcement through rewards and gamification. Adolescents preferred supportive and nonjudgmental feedback that encourages adherence while respecting autonomy. Younger adolescents placed greater emphasis on personalization and appearance, whereas older adolescents more readily conceptualized sensor-based monitoring functionalities.

**Conclusions:** Adolescents with scoliosis and their parents viewed smart monitoring as more than an adherence-tracking tool. Future smart orthosis systems may benefit from integrating clinically relevant sensing capabilities with user-centered features that support comfort, motivation, communication, and self-management. These findings provide user-informed design requirements to guide the development of future smart orthosis monitoring solutions and may contribute to the advancement of patient-centered rehabilitation technologies.

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**Keywords:** biomedical technology; focus groups; orthotic devices; patient participation; sensors; spinal orthoses; tracker; wearable electronic devices; user-centered design

# Introduction

## Background

Scoliosis is a 3-dimensional spinal deformity that typically emerges during the rapid growth years of puberty [1]. A spinal orthosis, often referred to as a brace, is the most widely recommended nonsurgical intervention and is effective in preventing curve progression when worn consistently for the clinically prescribed number of hours per day. The longer the wear time, the more prominent the treatment success [2]. However, adherence remains a significant challenge.

Patients need to accept and adapt to the treatment plans for a positive treatment outcome. Their daily routines may change to adjust to the treatment goals. School-going adolescent patients must use an orthosis, which is often uncomfortable, in daily school life and social participation [3]. Patients face emotional as well as physical challenges during the treatment period [4]. Research reports discomfort, heat, movement restriction, body image, and emotional strain as major barriers to adherence, with variation from patient to patient, leading to wide variability in treatment adherence [5].

Changes in technology have influenced all aspects of research, including health science. With more opportunities to use sensor-based technology, data from such devices are increasingly being explored for health monitoring. This type of monitoring is known as objective or smart monitoring, which uses sensor data. Patients with scoliosis can monitor their adherence to orthosis using a smart orthosis equipped with sensors [6,7]. Smart monitoring demonstrates relationships between wear time and curve stabilization, reinforcing its clinical value [8].

## State of Evidence

Orthosis wear has traditionally been assessed using patient-reported measures; however, objective sensor-based monitoring provides a more reliable and continuous assessment of actual wear time and adherence [9]. Sensor-based monitoring alone does not guarantee improved adherence, as success ultimately depends on patient engagement. Previous research suggests that adolescents and their parents generally view smart monitoring positively when used in clinical care [10].

## Rationale

The acceptability of smart spinal orthosis monitoring among adolescents is important because orthosis adherence is influenced by multiple factors, including age, sex, body image, quality of life, stress, family support, peer relationships, social environment, control over treatment, and comfort of using orthosis design [11]. Orthosis treatment outcomes depend on both adherence to clinical recommendations and the ability of the patient to manage treatment guidelines [12]. Understanding these experiences may help inform the design of future monitoring solutions.

## Gap and Motivation

Despite advances in digital health technologies, sensor-based monitoring of scoliosis orthotic treatment is not currently part of routine care in Norway. Informal discussions with clinicians and field observations highlighted the absence of such smart solutions in current practice. Therefore, there is a need to understand how adolescents with scoliosis and their families perceive smart monitoring and what they would find useful in a future solution.

The formative user requirements approach allows adolescents and parents to contribute their experiences, preferences, and ideas early in the design process. This may help ensure that future solutions address not only clinical needs but also the practical, emotional, and social challenges of long-term orthotic treatment. Although conducted in Norway, the findings may also be relevant to similar settings that consider local clinical, cultural, and regulatory contexts.

## Aim and Research Questions

The formative user requirements study was conducted in 2 sequential phases to identify user-driven design requirements for a future smart orthosis monitoring solution in Norway, involving adolescents with scoliosis and their parents. The study answers the following research questions (RQs):

- RQ1: How do adolescents and their parents envision monitoring and feedback to support orthotic management in everyday life?
- RQ2: What user-centered design requirements should guide the development of a smart monitoring solution for scoliosis orthosis management?

# Methods

## Study Setting

Orthosis treatment for patients with scoliosis is provided through specialist hospitals in Norway. These services are located in the 3 major cities of Oslo, Bergen, and Trondheim. In a 2012 study conducted at Oslo University Hospital (Rikshospitalet), Adobor et al [13] reported that among

752 patients with late-onset juvenile and adolescent idiopathic scoliosis, 86% (644/752) were girls. The study also highlighted the importance of early detection in facilitating timely nonsurgical management, including orthosis. A school-based scoliosis screening initiative may contribute to early detection, potentially increasing the number of patients identified for specialist assessment, orthosis treatment, and ongoing follow-up care. It implies that more patients who use orthoses may benefit from smart monitoring. Looking ahead, a digital solution tailored to the needs and preferences of Norwegian patients and their families could assist in scoliosis management.

## Study Design

Orthotic treatment adherence among adolescents with scoliosis is influenced by interacting physical, emotional, social, and clinical factors, making it difficult to separate the phenomenon from its real-world context. Therefore, this formative user requirements study involved adolescents with scoliosis and their parents to gain an in-depth understanding of user experiences, expectations, and design preferences for a future smart orthosis monitoring solution. By incorporating the perspectives of intended users during the early stages of solution development, the study aimed to generate insights that could inform the design of a monitoring solution that is relevant, acceptable, and responsive to user needs and treatment contexts [14].

The study was conducted in Norway within an established health care system and cultural context receptive to trustworthy technology-based health solutions. The intended end users of the future monitoring solution are adolescents undergoing long-term orthosis treatment for scoliosis. As smart monitoring technologies are not yet routinely used in scoliosis care, understanding user perspectives, preferences, and acceptability is important for informing future solution development.

The study was informed by published literature [15], discussions at national and international scoliosis-focused meetings, findings from workshops conducted with patients and a patient organization in 2023 [16], and field notes from informal discussions with clinicians.

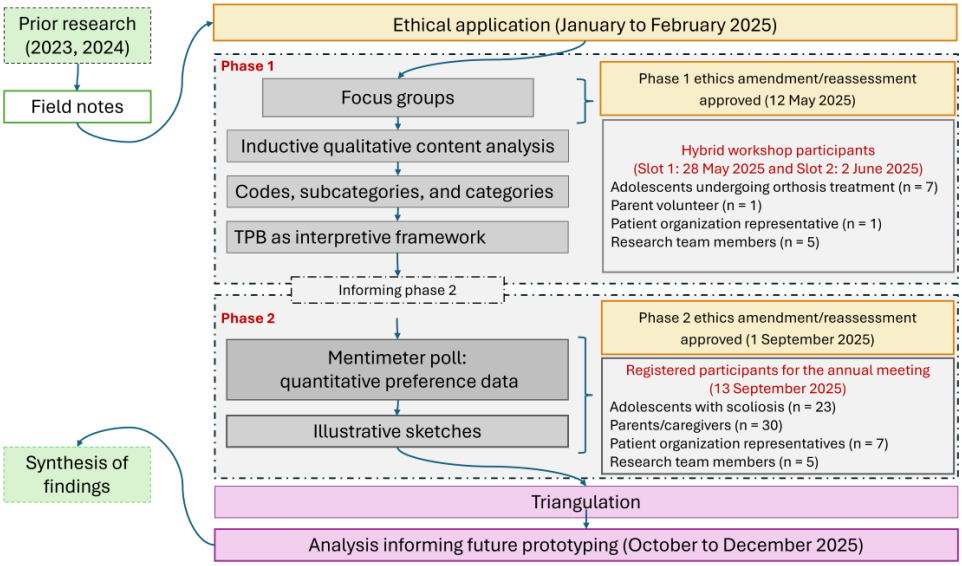
## Framework

### Overview

This study was conducted in 2 sequential phases. Phase 1 involved focus groups with adolescents undergoing orthotic treatment, while phase 2 used an audience response system (Mentimeter; Mentimeter AB) and sketching activities with adolescents and their parents. An experienced researcher and coauthor (NP) with expertise in user-centered research methods moderated all the stakeholder workshops. The moderator has more than 10 years of experience facilitating collaborative workshops, stakeholder engagement activities, and user-centered design processes within academic and applied research projects.

Figure 1 illustrates the study design for integrating multiple data sources to understand orthosis management in everyday life [17]. The theory of planned behavior (TPB) [18], which is a behavioral theory stating that attitudes, subjective norms, and perceived behavioral control together shape a person's intention and actual behavior, served as the interpretive lens. The TPB informed the study design and the interpretation of findings. We analyzed qualitative data inductively and then interpreted the resulting categories in relation to TPB constructs, including attitudes, subjective norms, and perceived behavioral control. TPB was therefore used as an interpretive framework rather than a predefined coding structure.

**Figure 1.** Overview of the study. TPB: theory of planned behavior.



## Phase 1: Hybrid Formative User Requirements Workshops

### Overview and Recruitment

Preparations for the workshops took place in 2025, as illustrated in Figure 1. Planning and ethical approval began in January 2025. The formative user requirements workshops were conducted in collaboration with the patient organization, which distributed a recruitment flyer on its website. The flyer described the study purpose, eligibility criteria, workshop format, participation options (online or in person), and research team contact information. Adolescents with scoliosis registered to participate in workshops exploring user needs for future orthosis monitoring solutions.

### Sampling

Inclusion criteria were being an adolescent with scoliosis aged between 10 and 17 years, living in Norway, and having experience with orthotic treatment. Workshops were scheduled after school hours, and participants could choose between online and in-person attendance. Gift cards were provided as a token of appreciation for participation.

Thirteen individuals registered for the workshops. Two members of the research team screened registrations against the eligibility criteria. The phase 1 focus group workshops explored participants' experiences and challenges related to orthosis treatment, as well as future design ideas for a smart brace. Adolescents who had undergone scoliosis surgery were excluded. Two registrants were awaiting initiation of orthosis treatment, and 1 registrant was aged 23 years and had completed orthosis treatment during adolescence; therefore, these individuals were not eligible. All registrants were informed of their eligibility status via email. Seven adolescents met the eligibility criteria and confirmed participation. One parent volunteered to support her daughter.

### Data Collection and Analysis

Data were collected through hybrid focus group discussions, where participants took part either in person or remotely via Microsoft Teams. The moderator (NP) guided discussions on each topic according to the workshop protocol (Table S1 in Multimedia Appendix 1), invited input from all participants, encouraged quieter participants to contribute, and managed the discussion to ensure that all topics were covered within the allocated time.

Given the hybrid format and the young age of participants, small groups were considered beneficial for promoting active participation, reducing digital fatigue, and allowing sufficient time for each participant to contribute. Participants who were available on both days were assigned to groups based on shared characteristics, with the aim of promoting homogeneity within groups and facilitating productive discussions.

Workshop data were audio recorded, transcribed, translated, and analyzed using qualitative content analysis by Graneheim and Lundman [19]. The primary researcher (AM) and 1 coauthor (PG) conducted the analysis with input from the multidisciplinary research team (AM: engineer; KS and MBJ: physiotherapists; NP and TS: product designers; MP: digitalization expert in the health sector; SA: orthopedic engineer; MFK: scoliosis patient organization representative; and PG: health and technology).

Meaning units were identified, condensed, and assigned codes. Similar codes were subsequently grouped into subcategories and main categories [19]. Additional details are provided in Table S2 in Multimedia Appendix 1. The resulting categories were subsequently interpreted through the TPB constructs of attitudes, subjective norms, and perceived behavioral control to better understand orthosis management and user requirements for future monitoring solutions.

## Phase 2: In-Person Formative User Requirements Workshops

### Overview and Recruitment

Insights from phase 1 focus groups informed the design of phase 2 data collection, an in-person stakeholder workshop led by the same moderator (NP) along with the multidisciplinary research team. The workshop was conducted during the annual meeting of the patient organization and was open to registered members. Seven representatives from the patient organization assisted with the planning, organization, and facilitation of the event. According to registration records, 23 adolescents with scoliosis and 30 parents or caregivers were registered to attend the meeting.

Findings from phase 1 were used to shape the topic and inform future prototype design needs through Mentimeter poll questions and workshop activities, focusing on challenges related to orthosis wear, treatment adherence, comfort, monitoring needs between clinical visits, technology preferences, and desired feedback mechanisms. We held separate workshop sessions for adolescents and parents to encourage active discussion and live poll-based reflections. Parallel Mentimeter polls captured perspectives from adolescent and parent respondents on these topics and stimulated engagement and discussion. The workshop protocols for phases 1 and 2 are provided in Table S1 in Multimedia Appendix 1. Participants completed Mentimeter polls and participated in facilitated discussions to explore pain, orthosis treatment challenges, monitoring needs between clinical visits, preferences for technology placement and data sharing, and desired feedback on brace wear and activity.

### Sampling

Participants for phase 2 were recruited among registered members attending the patient organization's annual meeting. Written informed consent was obtained using paper-based consent forms after participants received verbal and written information about the study. To maintain participant anonymity and avoid collecting identifying information, no background data were collected that would enable linkage between phase 1 and phase 2 participants; therefore, it was not possible to determine whether any individuals participated in both phases. There were no exclusion criteria for patients or their parents attending the meeting, and participation was voluntary. In phase 2, concepts were presented

as if introduced for the first time. The same moderator (NP) facilitated both phases 1 and 2 to maintain consistency with support from the multidisciplinary research team. This arrangement was to maintain patient participation anonymity.

## Data Collection and Analysis

### Mentimeter Polling

Mentimeter, a web-based audience response system, was used to collect stakeholder preferences and facilitate discussion [20,21]. Data were collected through anonymous polling during the workshop. Separate voting links were provided to adolescents and parents via distinct QR codes. The moderator, who had 10 years of experience facilitating stakeholder workshops, guided participants through each question, provided context, and encouraged responses and discussion. Responses were subsequently analyzed using descriptive statistics [22].

A downloadable Microsoft Excel file from Mentimeter served as the primary data source, providing information for each question, including the number of respondents and weighted average scores for each response option in the Mentimeter poll [23,24]. We used Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) to create visual comparisons of adolescents' and parents' preferences.

Mentimeter was used to collect real-time feedback during the workshops. Responses were collected anonymously to encourage open participation and facilitate the sharing of candid perspectives, particularly regarding personal experiences, preferences, and concerns. As responses were not linked to participant identifiers or registration records, individual responses could not be matched to participants, and response counts could not be verified against the registered participant list. Table S3 in Multimedia Appendix 1 provides additional details. Weighted average scores can be calculated by multiplying each Likert scale response option (ranging from 1 to 5) by its corresponding frequency, summing the products, and dividing by the total number of responses.

### Illustrative Sketching

The phase 2 workshop included a 30-minute sketching activity. Following a brief introduction, adolescents and parents worked separately, either individually or in small groups, according to their preference. Participants responded to the prompt, "If your orthosis could talk, what would you like to hear?" and identified treatment challenges, support needs, and desired features of a smart orthosis companion app.

Sketch templates, blank paper, pens, colored markers, and sticky notes were provided, and research team members offered practical assistance when needed. The sketches were reviewed and analyzed to identify participant perspectives and priorities relevant to future solution development.

### Data Sources and Triangulation

Data triangulation strengthened the content analysis by integrating data from 2 phases: focus groups with adolescents undergoing orthotic treatment (phase 1) and a stakeholder workshop involving adolescents and other stakeholders at the patient organization's annual meeting (phase 2). Findings from phase 1 informed the design of phase 2, and sketches generated during the workshops were used to support interpretation of the findings. Data from focus groups, Mentimeter polls, and sketching activities were triangulated to refine the emerging findings [25].

## Ethical Considerations

The study was approved by the Norwegian Agency for Shared Services in Education and Research (reference number 658746). In phase 1, which was conducted as a hybrid workshop, consent was obtained electronically through a QR code–linked online consent form before participation. In phase 2, written consent was collected on paper prior to the workshop. Participation was voluntary. Participants aged <16 years participated with parental consent and provided verbal assent after receiving age-appropriate information about the study. Participants aged ≥16 years provided their own consent and verbally confirmed their willingness to participate. Any future usability testing involving functional prototypes will require a separate ethical assessment.

# Results

## Participant Characteristics of Different Data Sources

Seven adolescents with scoliosis and 1 parent participated in phase 1, which consisted of 2 hybrid focus groups. Phase 2 involved a larger group of adolescents and parents who participated in Mentimeter polls and sketching activities. Group discussions, polling, and sketching enabled participants to share experiences, reflect on treatment challenges, and express preferences for future smart orthosis monitoring solutions.

Of the 7 participants, only 1 preferred a physical workshop, whereas the remaining participants favored a hybrid format. Participants preferred turning on the video, although it was optional, indicating they were interested in talking with other patients in a similar phase and even in sharing tips that might be helpful to those in the early phase of treatment. Thus, the discussion facilitated knowledge sharing among adolescents.

Table 1 illustrates the group dynamics of the adolescent patient participants over 2 days. The group dynamics of the 2 focus groups enabled in-depth exploration of needs, experiences, and ideas for future sensor-based adherence solutions. Older adolescent patients in the focus group were quite active in discussions with peer patients of a similar age. On both days, we had at least one patient who received treatment outside Norway, which helped with similar discussions on both days. The 2 focus group discussions explored adolescent patients' attitudes, challenges to treatment adherence in society, perceived expectations, and aspirations for mobile-based apps that could support them during treatment.

**Table 1.** Focus group dynamics from phase 1.

| Dynamics | Details |
|---|---|
| Participants, n | |
| Adolescents with scoliosis | 7 |
| Parents | 1 |
| Focus groups, n | 2 (4 participants each) |
| Participation mode, n | |
| Online | 7 |
| Physical | 1 |
| Age (years), range | 10-17 |
| Place of treatment (adolescents, n=7), n | |
| Within Norway | 5 |
| Outside Norway | 2 |
| Prescribed orthosis wear (hours per day) | 23 |
| Duration of orthosis wear, range | 1 month to 4 years |

Formative user requirement design ideas were captured with moderated discussion in phase 1, but its scope was naturally limited by the small number of participants. The phase 2 activities, therefore, served to refine the insights within a larger group of Norwegian adolescents and their families. The topic of discussion was derived from phase 1. In the parent poll, 25 of 30 individuals participated (20-25 responses per item). In the adolescent poll, 26 individuals logged in, with 23 to 26 responses per item. Given the fully anonymous design, all self-identified eligible respondents were included in the analysis. For every topic, 2 Mentimeter presentations were prepared to make the discussions interactive. The workshop protocol is presented in Table S1 in Multimedia Appendix 1.

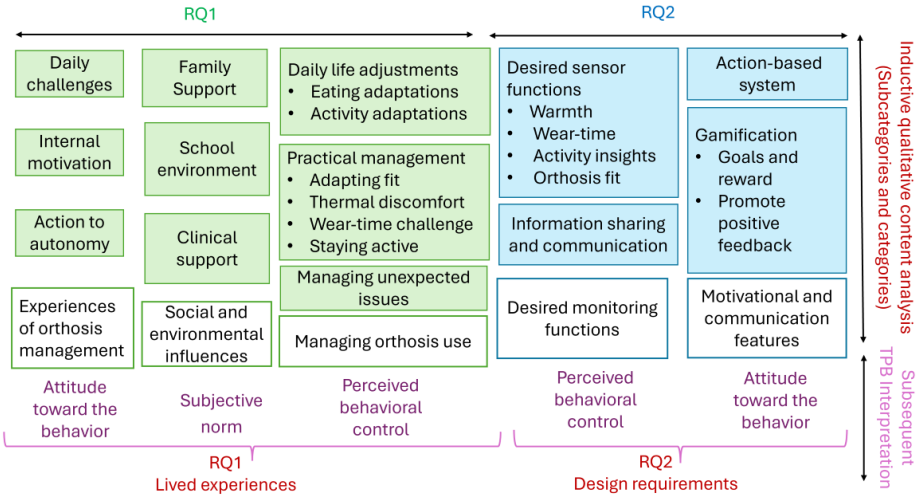
Families contributed additional insights by creating illustrative sketches, individually or as group submissions, to visualize their wishes for future solutions. These sketches often highlighted discomfort zones, perceived barriers, and design preferences, offering rich contextual depth beyond verbal data.

## Phase 1: Hybrid Formative User Requirements Workshops

### Overview

Findings from the focus groups, Mentimeter polls, and sketching activities converged and are organized around the 2 RQs. Inductive qualitative content analysis identified 5 main categories and several subcategories describing participants' experiences, support needs, and preferences for future smart orthosis monitoring solutions (Figure 2). As participants' views on symptom monitoring and feedback were closely informed by their day-to-day experiences of symptom management, findings related to current challenges are presented first to provide context for the monitoring and feedback needs and preferences described subsequently. These categories were subsequently interpreted through the TPB to explore how the findings related to attitudes, subjective norms, and perceived behavioral control.

**Figure 2.** Overview of categories and subcategories identified through inductive qualitative content analysis and subsequently interpreted using the theory of planned behavior (TPB). RQ: research question.



## Research Question 1

This section addresses RQ1: How do adolescents and their parents envision monitoring and feedback to support orthotic management in everyday life?

The three main categories identified under RQ1 were experiences of orthosis management, social and environmental influences, and managing orthosis use (Figure 2). Together, these categories show how adolescents experience orthosis treatment in daily life and the monitoring and feedback they perceive as valuable.

### *Experiences of Orthosis Management*

Adolescents described orthosis treatment as a long and demanding journey shaped by fluctuating levels of pain, discomfort, and emotional strain. Common challenges included stomach pain, skin irritation, heat, and the sense of being physically constrained. Some participants reported modifying prescribed wear time because of these accumulated challenges.

#### Daily Challenges

The 23-hour clinical prescription to wear the orthosis almost the full day was the most frequently reported daily challenge, as they ended up with reduced hours:

> *I often ended up wearing it around 20 to 21 hours.*

> *I probably wear it around 18 hours a day, maybe a bit less.*

Patient participants recalled substantial pain and pressure at the beginning of treatment, followed by gradual adaptation. Adolescents reported a wide range of challenges in meeting daily treatment requirements, which shaped their overall attitude toward treatment adherence, including the physical, emotional, and practical demands of orthosis wear, alongside expectations for digital monitoring. As one adolescent described:

> *I remember saying [to physicians] many times that I was in a lot of pain, especially stomach pain. I had mentioned the discomfort throughout the entire treatment.*

Patients often looked forward to moments when they could take off their orthosis, as it makes them uneasy and physical restrictions make the situation harder:

> *I could have taken it off for longer if needed, especially during certain times, though I haven't usually done that.*

In addition to physical challenges, adolescents faced emotional challenges as part of the long-term treatment, as explained by a patient:

> *The hardest part was more the mental side of things—feeling kind of trapped inside this plastic shell for 23 hours a day.*

Patients described the hardship of orthosis wear as follows:

> *[I]t's really hard to stay motivated when you're in a lot of pain…and honestly, wearing the orthosis isn't something you really want to do.*

#### Internal Motivation

Motivation for adhering to orthosis treatment stemmed from both internal and external sources. Two adolescents expressed a feeling of inner motivation that supported orthosis adherence. This motivation was often rooted in confidence in the treatment process and a belief that their efforts were contributing to meaningful health outcomes in the future:

> *For me, the orthosis was actually very motivating to wear. It helped me stay focused, because I knew it was helping my body in that moment.*

> *[A]t least I had made an effort...to make things better. So in 20 years, if my back gets really bad, I can live with the feeling that I really tried.*

The inner strength helps handle discomfort and strengthens commitment to maintaining the prescribed wear time. The joy of learning about reduced orthosis wear time after years-long dedication to prescribed routines, emphasizing that hard work helps in reducing orthosis wear time, and clinical assurance of reduced wear time over successful treatment outcomes can strengthen from within adherence to treatment goals:

> *I will begin reducing it [for 2.5 years she wore 23 hours orthosis] to 16 hours....It will be nice!*

It is also noted that the urge to avoid surgery is a powerful internal motivator. Adolescent patients also drew motivation from observing the stability of their scoliosis curve, seeing that the condition remained unchanged or remained below surgical thresholds, offering relief and reinforcing the value of their efforts:

> *I wore it for a little over a year before I found out I was done with it. I also found out I was just below the threshold to avoid surgery.*

Another participant similarly shared:

> *I was told to keep tightening it more and more to apply increasing pressure. It was also about trying to correct the curve and prevent surgery.*

Together, these narratives illustrate that inner inspiration guided adolescents to bear the present challenges with anticipation of a better future. This inner motivation helped

adolescents manage discomfort, adhere to bracing recommendations, and remain committed to treatment despite its demands.

### Action to Autonomy

Adolescents reported that they do not keep any form of journal, but they described that receiving supportive feedback would be meaningful if it helps them manage the orthosis without having to consciously track their orthosis use:

> *When the person is active, it could track that time too. So, I wouldn't have to constantly think about whether I'm wearing it right.*

Adolescents currently rely on simple mental calculations or informal tracking through conversations with parents:

> *I usually track it in my head, like, "Okay, it's been an hour now," then I look at the clock and do the math...and so on.*

> *I kind of used my mom as one [refers to journal that tracks]—I talked to her a lot.*

Adolescents valued autonomy in their daily lives and preferred supportive digital solutions that could reduce the burden of manually tracking orthosis use.

> *I think it's best not to have that pressure, of course.*

## *Social and Environmental Influences*

Environmental factors shaping adolescents' adherence included social support from school peers, parents, and clinicians, together with their responses to unexpected situations.

### School Environment

The school environment explains what others think about adolescent patients: supportive treatment actions, open communication, and helping to reduce stigma.

> *That [teachers are supportive toward their students] made it much easier to speak up when I needed something.*

Teachers play a significant role in supporting basic needs and education.

> *What really helped was having people around me who supported me—like the final mentors or helpers who understood what I was going through with the orthosis.*

Their openness to discussing orthosis use fostered curiosity rather than discomfort among classmates.

> *I had to figure out how to do things—like how to eat at school, or even just get dressed.*

Adolescent patients are happy when friends assist with practical tasks and support them during difficult periods.

### Family Support

Parents played a prominent role in supporting adolescents' orthosis-wearing routines, often managing logistics, such as scheduling follow-up appointments and communicating frequently with hospitals.

> *They [family] were really good at supporting me through the whole process" and "they [family] did their best to help.*

Parental feedback typically focused on affirming that the orthosis was being worn the right amount. Adolescent patients appreciate encouragement rather than criticism. This supportive tone can help sustain adherence and provide emotional reassurance during treatment:

> *She'd say things like, "Just wear it for a few more hours, then you can take a 10-minute break—keep going." She was also the one I talked to when I was struggling emotionally. My parents always wanted me to share as much as I felt comfortable with.*

Although most felt comfortable sharing data with parents, not all days are the same, and adjustments might not be possible with smart real data. It can create a reason for stress if a patient fails to wear it one day. It becomes difficult to handle parents at the end of the day:

> *So I think having that little bit of freedom is really important. I think it's best not to have that pressure, of course.*

Likewise, another patient participant expressed fear that it can be a reason to stress if the information is not positive:

> *Not too much negative feedback, but maybe something gentle like, "She could wear it a bit more," without making it feel bad. Because it's really important to wear it as much as you can manage.*

To sum up, the discussion is particularly noteworthy, as it highlights a sensitive area that also relates to the TPB by reflecting the impact of environment, namely, subjective norm, which plays an important role in shaping complex human behavior. This remains an open area that requires further exploration in phase 2 with larger populations.

### Clinical Support

Clinical aid is supportive in sharing the orthosis treatment. Adolescents reported interactions with clinicians who have limited knowledge of scoliosis and with specialists who respond quickly via digital communication.

> *[I]t was kind of hard-to-get appointments [with clinicians] and such.*

Some experienced regular and formal follow-ups, while others received timely guidance from clinicians abroad:

> *If it got bad, we could send a message or usually an email and ask if we could get an appointment. But it wasn't something we really thought about doing very often.*

Stability in communication improves once they are assigned a regular physician, often supported by active parental involvement.

### Managing Orthosis Use

Patient belief refers to the individual's confidence that they have the new means or find opportunities to carry out a behavior. In essence, it answers the question: Can I, as a patient, do it? When adolescents with scoliosis experience barriers such as discomfort or difficulty meeting day-to-day needs, they draw on personal resilience and adaptive strategies to survive and thrive within their circumstances. These beliefs shape whether they see obstacles as limiting or as conditions they can learn to manage.

## Daily Life Adjustments

### Eating Adaptations

Mealtimes posed particular difficulties, as fullness often tightened the orthosis and required loosening or switching to smaller meals. Adolescent patients agreed and described having a consistent pressure point around their stomach after meals.

> *When I eat, my stomach expands,...and then I have to loosen the orthosis.*

One of them reported adapting her eating habits by choosing smaller, more frequent meals to reduce discomfort from the orthosis. In addition, another patient feels that the adjustment made it difficult to maintain adequate nutrition:

> *I became quite undernourished and lost a lot of weight because I just couldn't manage to eat enough. The orthosis was so tight, and even though things got better eventually and I kept going.*

One parent mentioned, "We are simply trying to have the dinner meal during her free time." Eating habits shifted to accommodate tightness around the stomach, frequently resulting in smaller meals or weight loss.

### Activity Adaptations

Integrating the orthosis into everyday routines requires ongoing adjustment. "I get exhausted, and there are things I can't do—like lifting as much as others—which can be a challenge," reported an adolescent patient. Most of them accept and adapt to lead a safer life. Adaptations range from adjusting hobbies to suit the new requirements to independent daily living, for example:

> *I was told not to lift anything too heavy. Like, for example, if we're renovating or moving a sofa, I should ask someone else for help.*

To sustain engagement, many adolescents experimented with different sports and physical activities, testing what worked with the orthosis and what felt motivating. Climbing, rowing, martial arts, and swimming were frequently mentioned as activities that helped maintain both physical ability and morale, allowing participants to stay active despite the constraints of treatment:

> *I have a dad who does martial arts, so I thought I'd try that again. It wasn't exactly recommended, but they didn't say it was a bad idea either. So I tested it a bit.*

Patients with scoliosis adapted activities, continued sports and hobbies with some modifications, and relied on supportive adults or instructors to help adjust exercises where needed, despite remaining active in activities such as hiking, musical performance, martial arts, or Scouts:

> *My trainer adjusts exercises so I don't do anything that could strain my back, which lets me stay physically active. I'm also part of the Scouts, where we mostly go on hikes.*

> *I play tennis and go to the gym and stuff like that. The physiotherapists at the place where I got my orthosis just told me I could do whatever I wanted, as long as it didn't cause too much pain or push me too hard.*

Workshop discussions showed that adolescents' efforts to stay active were not fully matched by the generic advice they received:

> *I got more or less the same advice from the hospital: not to push myself too far, but still try a little—to see what I'm comfortable with.*

Adolescents described extensive routine adaptations to manage the physical and emotional demands of orthosis treatment.

## Practical Management

Adolescents conveyed how a patient's sense of control over orthosis-wearing routines was shaped by practical challenges and the strategies they developed to manage them. These were reflected across subcategories: adapting the fit, managing thermal discomfort, maintaining wear-time, and staying active within limits.

### Adapting Fit

Adolescents described several strategies for managing pain, discomfort, and the practical demands of orthosis wearing. Initial fitting and adjustments to avoid discomfort were often lengthy and uncomfortable, especially for those traveling long distances for appointments:

*Since it was quite far away, I usually stayed for two days for various reasons. I think the first time I got the corset; I was there for a week to get it adjusted.*

Many experienced poking or pressure until modifications were made. Over time, patients learn to recognize correct positioning and adjust the orthosis independently, applying the required strap tension in accordance with clinical guidelines:

*I can also tell just by how it feels on my shoulders if it's not positioned right—because after a while, the pressure changes.*

This embodied awareness, such as judging fit by how the straps or shoulder areas felt, particularly after eating, helped patients with orthosis adapt and maintain daily routines:

*It's just pressure mostly that I feel while I'm eating.*

*Sometimes we try to loosen the orthosis just a little bit during the meal.*

Another adolescent described how practical experience helped her learn:

*[W]hen I eat, my stomach expands—because I'm human—and then I have to loosen the orthosis. Then once I've finished eating and some time has passed, I have to tighten it again. So, it's more of a practical issue. It's a bit annoying, but that's just how it is.*

## Thermal Discomfort

All adolescent patients who used spinal orthosis for treatment reported that summer was the most uncomfortable season for orthosis wear, with the heat inside the orthosis intensifying physical discomfort and making daily routines increasingly challenging on hot days.

*Summer wasn't very comfortable either since it got really warm inside the orthosis.*

*When it was hot, the orthosis felt really tight and uncomfortable.*

*There were times when I felt like I was overheating inside the orthosis, and it would press sharply against me.*

Another patient explains why she hates to be in the sun on a sunny day in Norway:

*It gets a bit clammy, and kind of warm too—it's almost like wearing a wool sweater around your stomach...so you get a bit hotter. But mine has large breathing holes, and it's a relatively small orthosis, so it's a lot more manageable. Still, when it's 30 degrees outside, I really don't want to be out in the sun.*

Patients experimented with clothing that was worn under orthoses, most often selecting thin cotton undershirts under orthosis. The parent reported that ventilation was provided by the orthosis designer, which helped relieve her daughter's discomfort in the first summer: "it was really hot then, so she also got a lot of ventilation holes." The concern with thermal discomfort is that most patients fail to adhere to treatment:

*I was supposed to wear it [orthosis] 23 hours a day, but it got a bit warm and I never quite managed that fully. So, I think I just tried to do my best.*

## Wear-Time Challenges

Most patients using orthoses described the feeling of being overwhelmed by the idea of wearing the orthosis continuously, noting that prolonged use could feel "a bit scary," particularly when the orthosis became hot or uncomfortable.

*I think I just tried to do my best. I could…but it felt a bit scary—like wearing it for so many hours straight.*

Adolescents reported difficulty achieving the prescribed 23 hours of daily orthosis wear, often due to heat, discomfort, and lifestyle constraints. It is often difficult to ensure 23 hours of orthosis wear daily:

*I never really did the strict 24/7 thing right away. I just keep it on, and then I take it off to change clothes or shower and then put it right back on again. That's just how I do it.*

One patient reported managing close to full-time wear around 20 to 21 hours per day, while another patient found the requirement "extremely challenging" and was only able to maintain 18 hours.

*I am supposed to wear it 23 hours a day, but I often ended up wearing it around 20 to 21 hours.*

*I don't quite manage 23 hours a day—it's a bit difficult...I probably wear it around 18 hours a day, maybe a bit less. But I haven't had it for very long yet, so I guess I'm still getting used to it.*

## Staying Active

All adolescent patients highlighted the value of staying active even when the orthosis felt restrictive. They explored enjoyable hobbies and incorporated prescribed exercises to maintain movement and confidence, with some noting that physiotherapy was particularly helpful.

*I went to a physiotherapist for quite a while after my treatment, and that really helped.*

At the same time, they were cautious about overexertion, underscoring the need to balance activity with the risk of triggering pain:

*[S]ometimes I feel like I can't push myself fully...there's always this fear of triggering that intense pain—which doesn't go away quickly.*

These narratives illustrate how adolescents worked to remain active while respecting the physical limits imposed by the orthosis.

### Managing Unexpected Issues

#### *Treatment and Travel*

Those receiving treatment abroad noted more responsive communication systems, including email or other structured channels that provided more predictable follow-up:

*If we have questions or if something breaks on the orthosis, they're [treatment outside Norway] there to help.*

*[I]t's expensive to travel [treatment outside Norway] all the time, yeah...And if any problems did come up, they were very available by email.*

#### *Special Occasions*

Adolescents described the need for timely guidance when unexpected issues appear with orthosis wear, highlighting that quick access to clinicians could play a clinically significant role in managing such situations. In current practice, patients find difficulties with pre-booking appointments, which they view as an impractical option during acute concerns. Calling directly was their least preferred option.

*If it got bad, we could send a message or usually an email and ask if we could get an appointment. But it wasn't something we really thought about doing very often.*

Patients across both groups consistently identified parents as their first point of support during unpleasant and uncertain situations, emphasizing the central role of parents in direct crisis management.

*If something was bothering me, they [mom and dad] wanted to know so they could help.*
*I was younger then, and my mom was very involved—she spoke on my behalf and helped express my needs.*

## Research Question 2

This section addresses RQ2: What user-centered design requirements should guide the development of a smart monitoring solution for scoliosis orthosis management?

Two categories were identified that describe user-centered design requirements for future smart orthosis monitoring solutions: (1) desired monitoring functions and (2) motivational and communication features (Figure 2). These categories capture participants' expectations regarding sensor-based monitoring functionalities, information sharing and communication needs, and motivational design features that could facilitate adherence to and support long-term orthosis management.

### *Desired Monitoring Functions*

#### Desired Sensor Functions

Adolescents envisioned smart orthosis features, meaning orthoses that have sensors to collect real data, which could meaningfully support daily management by providing clear, helpful information rather than adding burden.

#### *Warmth*

Across the 2 focus group discussions, all participants described how challenging it is to wear an orthosis in the summer.

*Maybe something with moisture and temperature, because sometimes it gets really hot.*

Patients suggest monitoring to protect them from overheating:

*So, something that could stop you from overheating on hot summer days would be really useful.*

Adolescents suggest that having sensors could help manage heat, noting that summer wear was particularly challenging and that temperature feedback, or even a cooling option, could guide brief removal of the orthosis for comfort:

*[M]aybe a cooling system...that measures the temperature and can send an emergency alert if it gets too hot—so you know [and act].*

*[O]n the hottest summer days, that you need to take a break or drink some water, so you don't overheat.*

#### *Wear Time*

Time tracking was another highly desired feature, as adolescents reported difficulty monitoring orthosis wear time themselves and noted that parents often took responsibility for this:

*She'd [mom] say things like, "Just wear it for a few more hours, then you can take a 10-minute break—keep going."*

An automatic summary would allow them to "live more freely" without having to calculate each day:

*[I]f it's really smart, maybe it doesn't need to track how many times I've dropped it on the floor when I've taken it off. I don't really need to know that myself.*

Another patient added:

*It would just know that I was active and that it still counted.*

One patient reported how her parents helped to track the hours of orthosis wear time:

*I never kept a journal, but I kind of used my mom as one—I talked to her a lot. She often kept track of how many hours I wore the orthosis, and she was the one who pushed me when I hit a bit of a mental low...which, unfortunately, happened quite often.*

### Activity Insights

Adolescent patients also emphasized the true value of activity-related insights, suggesting that sensors could help monitor safe movement patterns or muscle activity:

*I feel like when I'm walking or running with the orthosis on, I tense up my muscles. I think if my orthosis were smart, it would let me know about that.*

Another patient suggested:

*[D]etect muscle tension...or notice certain things Like if you moved a little or needed more support.*

### Orthosis Fit

Participants highlighted the importance of monitoring orthosis fit, as daily adjustments to pressure, especially after meals, were necessary to avoid discomfort or choking sensations. A system that helps ensure correct fit and provides reassurance would not only support adolescents but also relieve parents who assist with everyday orthosis routines.

*It [smart orthosis] could say, "It's most effective during these hours."*

## Information Sharing and Communication

Adolescents reported that they did not always communicate their planned experiences during clinical visits and often relied on parents to voice concerns on their behalf:

*My dad was there and helped me speak up [to physician] about it [challenges].*

*I often held back from saying anything [to physician].*

The parent herself reported that it is meaningful to know about her daughter's orthosis-wearing information:

*I think the orthosis should be able to tell whether it's been put on correctly.*

A smart monitoring system that provides useful, nonstressful summaries was viewed as beneficial, particularly if it could support communication not only with clinicians but also with parents, who play a prominent role in daily orthosis management.

*Gives to my parents [update] should be more like encouragement*

*That [orthosis with tracker] would be really helpful for families too.*

However, feedback should avoid situations that could demotivate patients who are doing their best. Adolescents are afraid of bad days when they fail to meet the requirements even after catching up with all other days. Hence, they wish to have control over what information was shared and when.

*I think having that little bit of freedom is really important.*

*[D]o it [track] like...in a way that doesn't make the child feel monitored.*

## Motivational and Communication Features

### Action-Based System

Participants proposed a smart monitoring system that included wear-time tracking, temperature and moisture monitoring, activity logging, and pressure alerts for hotspots under straps or near the arms:

*You could have had a system that included both of those things [activity and heat when orthoses are worn]. It's definitely thinking outside the box, but...it would've been really cool.*

Adolescents expressed a preference for feedback that helps them wear the orthosis longer, delivered in timely, measurable, and useful ways. One adolescent suggested that orthosis fit adjustments could be automated to reduce the need for human involvement:

*People would just say, "You just have to wear it a bit longer," but if there were a sensor that could detect when the pressure was too high—like over a certain level—then you'd know when to adjust it a bit and where to tighten or loosen it.*

Some envisioned more advanced concepts, such as automated micro-adjustments to relieve pressure, though such ideas would require careful clinical testing:

*Sensors that could tighten themselves and detect how it needed to adjust itself, and how to straighten itself automatically.*

### Gamification

#### Goals and Reward

Adolescents are motivated by rewards. It can be implemented by sharing the sensor data with a mobile app that the user can see and follow.

> *I do think something like an app could be helpful to motivate you to wear the orthosis more.*

> *[A]n app with a tracker—something visual where you could set goals and see your progress.*

Patients suggest gamification elements, suggesting that sensors could communicate with a mobile app providing reward-based features.

> *"You've reached your goal!" That kind of feedback would be really encouraging.*

#### Alerts to Adjust

Alerts could prompt patients to adjust their routines, for example, to remove the orthosis when it becomes too warm or to modify wear time, and rewards could be offered for each hour the orthosis is worn:

> *Something that measures the temperature and can send an emergency alert if it gets too hot—so you know, for example, on the hottest summer days, that you need to take a break or drink some water, so you don't overheat.*

Incorporating these gamified features was seen to make orthosis use more engaging.

> *How many hours you wore it—that information just be stored in the app in a fun way.*

#### Promote Positive Feedback

Adolescents also emphasized that feedback should be motivating and avoid any negative tone that might discourage use.

> *Maybe a timer or some motivational words could have helped.*

> *She's wearing it the right amount, great job! She could wear it a bit more, without making it feel bad.*

All adolescents agreed to the point that negative feedback is to be avoided:

> *It doesn't have to tell me everything directly, but maybe it could avoid saying negative things.*

Any feedback that demotivates the patient needs to be delivered in a way that encourages each step the patient takes toward adherence.

> *Like you could earn points if you wore it for a certain number of hours and so on.*

Even if it is reduced hours, the patient tries to wear it. Every hour if rewarded can be motivating to wear the orthosis more, was the suggestion from the patient perspective.

> *Every hour you wear it, you get a small reward in the game...that cannot be negative.*

The system can decide what is motivating to the user and share those details that support.

> *Maybe it could show percentages instead—like 100%, or maybe 5%—just a little red number to show it's low, but not something that feels obviously bad.*

The content analysis showed that patients with scoliosis with personal experience using orthosis identify user needs and design expectations for a future smart orthosis, which can be mapped to the 3 constructs of the TPB, which explains the overall combined effect of complex human behavior. The findings offer rich insights from a small population and provide a foundation for collecting more targeted data on treatment challenges and smart monitoring needs in larger cohorts.

## Phase 2: In-Person Formative User Requirements Workshop With Families

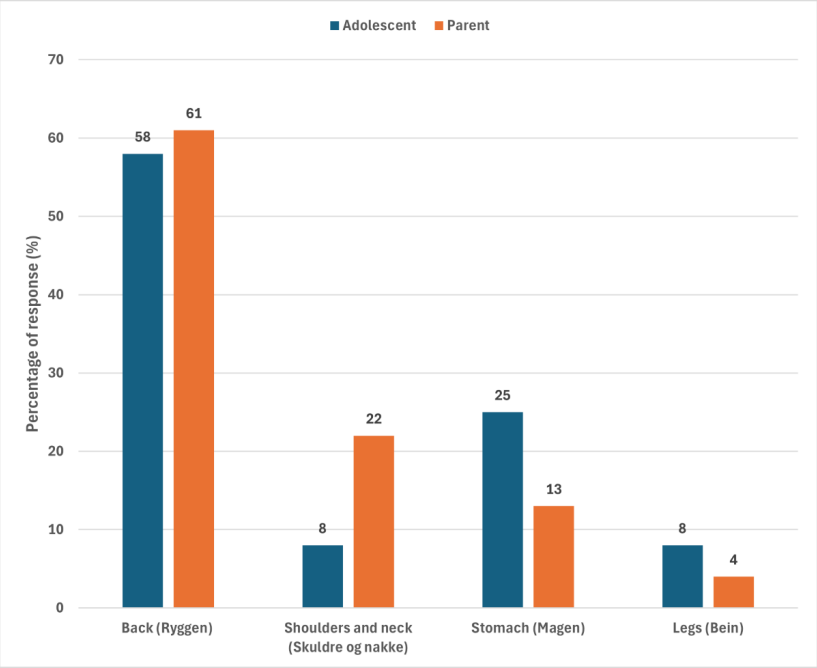
### Research Question 1

Phase 2 findings were examined alongside the phase 1 categories to explore convergence across data sources. The anonymous polling approach generated high levels of engagement and facilitated candid stakeholder feedback. Although response counts varied across questions and could not be linked to individual participants, the data demonstrated consistent trends across stakeholder groups. These trends provided valuable direction for identifying user needs, preferences, and areas of concern, thereby supporting the study's co-design objectives. The benefits of fostering trust and open participation likely outweighed the loss of traceability at the individual level. Multimedia Appendix 2 presents the response counts for each topic discussed in this Results section. Table S3 in Multimedia Appendix 1 provides additional details and context for the Mentimeter poll findings.

Findings suggest that adolescent patients experience several challenges. Patients were gradually introduced into the discussion through prompts that encouraged them to reflect on themselves. The first topic to reflect on was how well the patient (or their teenager) slept the previous night; both the adolescent poll and the parent poll indicated that they had slept well. Subsequent discussion was a comparative analysis.

In phase 1, we noted that eating habits were reported to be challenging and painful. The subsequent discussion focused on pain experienced during the previous 3 months. Adolescents with personal experience reported higher pain intensity (mean 3.64/10, SD 2.14; n=25) than parents (mean 2.72/10, SD 1.81; n=25). Regarding pain location, both adolescents (58%, 14/24) and parents (61%, 14/23) identified the back as the most painful body region. Stomach pain was the second most frequently reported pain location among adolescents (25%, 6/24), compared with parents (13%, 3/23), whereas shoulder and neck pain were reported more frequently by parents (22%, 5/23) than by adolescents (8%, 2/24) (Figure 3). The higher reporting of stomach pain among adolescents is consistent with qualitative data describing adjustments to orthosis use during meals because of abdominal pressure and stomach discomfort. This may reflect differences between adolescents' lived experiences of orthosis wear and parents' perceptions of pain location. These findings suggest convergence between the qualitative and quantitative data regarding the challenges associated with orthosis wear.

**Figure 3.** Mentimeter poll results on "pain in the body in the last 3 months."

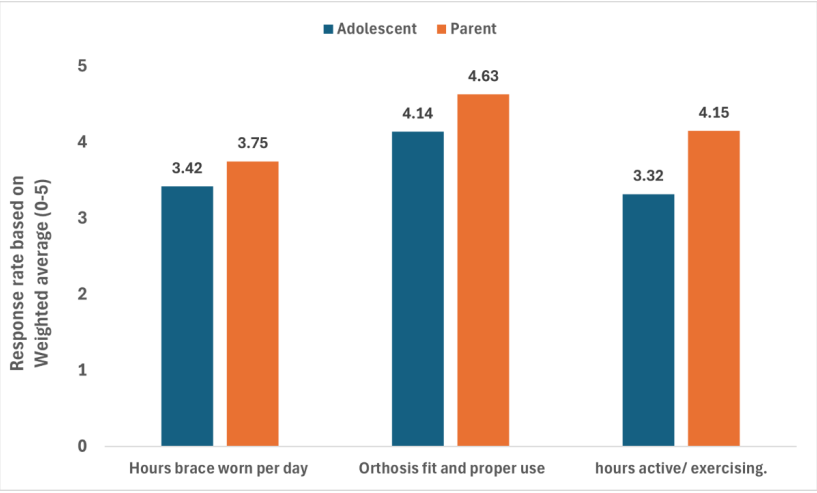



Orthosis adjustment is a common issue among adolescents using orthoses, as many routinely loosen or tighten the orthosis after heavy meals to avoid feeling choked while waiting for food to digest.

## Research Question 2

Users were also asked what they wished to track, focusing on wear time, correct orthosis use, and activity level. Parents and adolescents showed similar priorities, with only small differences between options (Figure 4).

**Figure 4.** Mentimeter poll results on "what is important to monitor."



To understand sensor placement, another Mentimeter poll was used after varied suggestions. In the online discussion, one adolescent mentioned wearing a T-shirt beneath the corset. Hence, options were given to consider a T-shirt, orthosis, and wearables to use when orthoses are not used, a completely different solution. Voting revealed a clear preference in both groups for sensors placed directly on the orthosis, as presented in Figure 5. As many adolescents expressed interest in gamified solutions, participants were also asked about the frequency of their feedback. Most preferred receiving feedback once per week on weekdays, with weekend alerts being the least favored (Figure 6).

**Figure 5.** Mentimeter poll on the preference of sensor location.

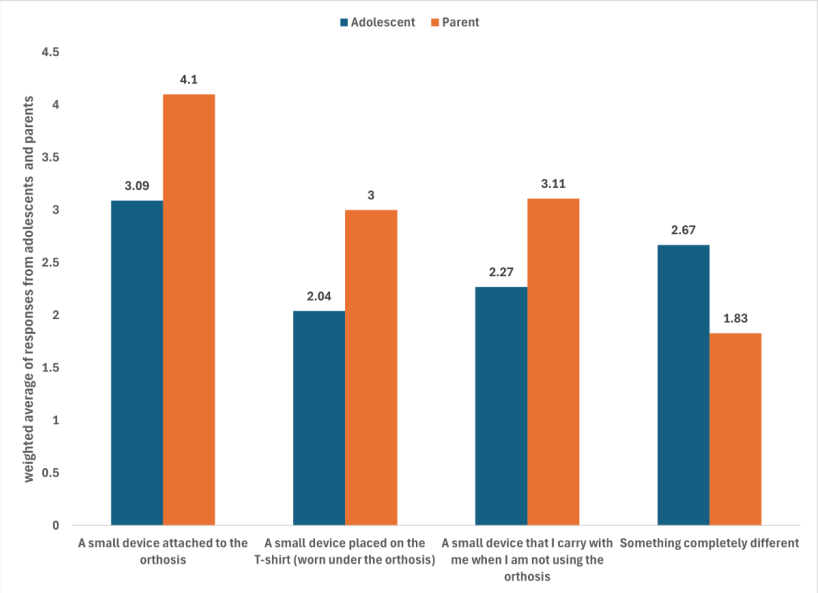
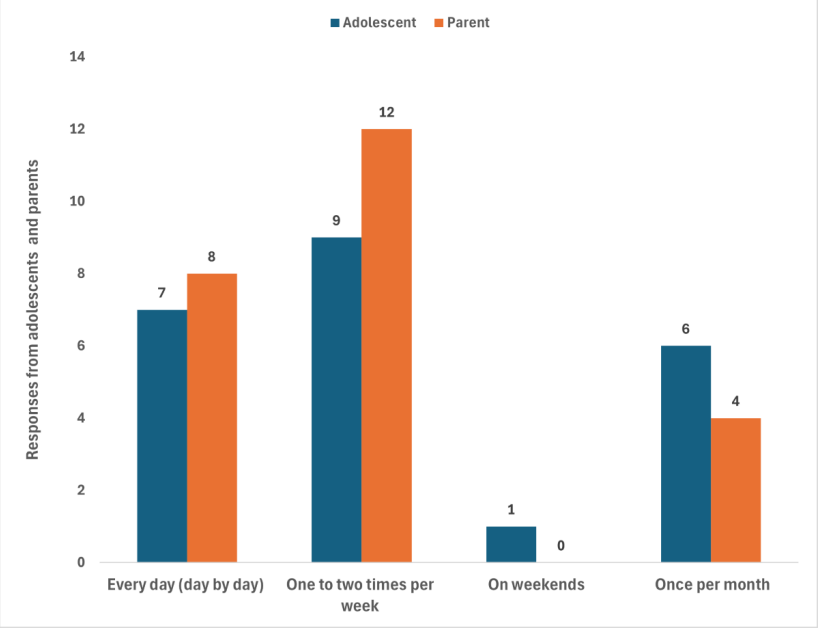


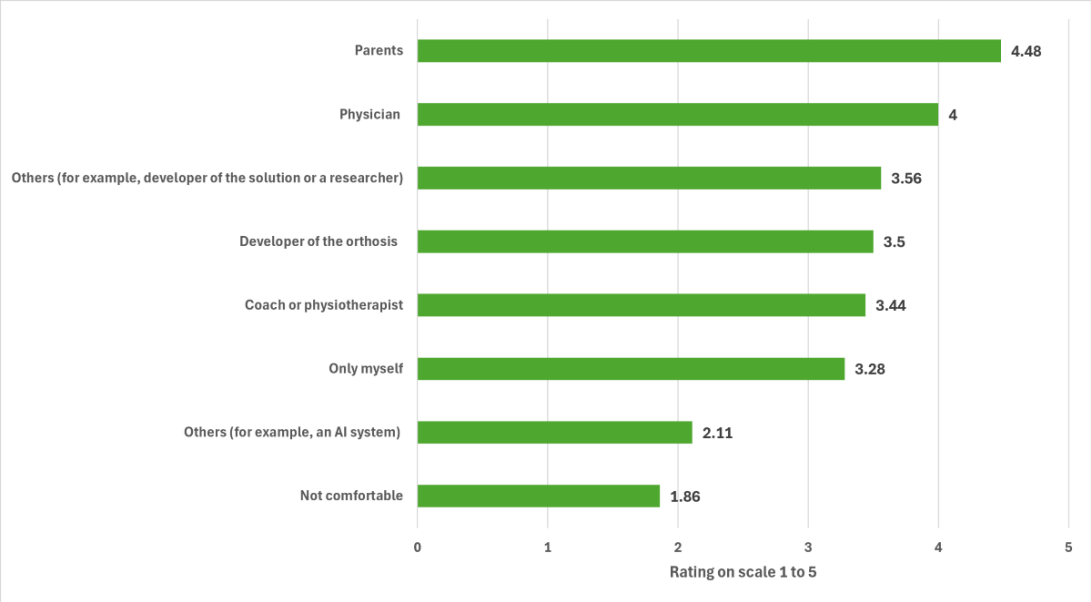

**Figure 6.** Mentimeter poll results on when to receive alerts.




In phase 1, discussions on social and environmental influences, including the role of family and the broader environment, were open-ended. Adolescents expressed concerns about the potential stress associated with data sharing and emphasized the importance of retaining control over the data. Four of the 7 participants reported being comfortable with sharing such data. To further explore adolescents' data-sharing preferences and identify trusted recipients, these findings were subsequently examined in a larger sample. Norwegian adolescents reported the greatest comfort sharing information about their orthosis use with their parents (mean 4.48, SD 0.87; 14 of 21 respondents selected the highest rating of 5) and physicians (mean 4.00, SD 1.26; 10 of 21 respondents selected a rating of 5 and 6 selected a rating of 4). Moderate comfort levels were reported for sharing information with researchers or solution developers (mean 3.56,

SD 1.62; n=18), developers of the orthosis (mean 3.50, SD 1.50; n=20), and coaches or physiotherapists (mean 3.44, SD 1.38; n=18). Refer Figure 7 and Table S3 in Multimedia Appendix 1. Adolescents reported moderate comfort with keeping information about their orthosis use only to themselves (mean 3.28, SD 1.78; n=18). Parents demonstrated a broadly similar pattern when considering information about their child's orthosis use, with the highest comfort sharing with physicians (mean 4.67, SD 0.80; n=21). Both adolescents and parents reported limited comfort sharing orthosis use information with AI-based systems (adolescents: mean 2.11, SD 1.41; n=18; parents: mean 2.75, SD 1.68; n=20), and a subset of respondents in each group indicated that they were not comfortable sharing information at all (adolescents: mean 1.86, SD 1.51; n=14; and parents: mean 1.64, SD 0.93; n=14). Overall, the survey findings suggest that Norwegian adolescents were most comfortable sharing their orthosis-use information with their parents, followed by physicians.

**Figure 7.** Adolescent patients' poll on preferred data sharing.

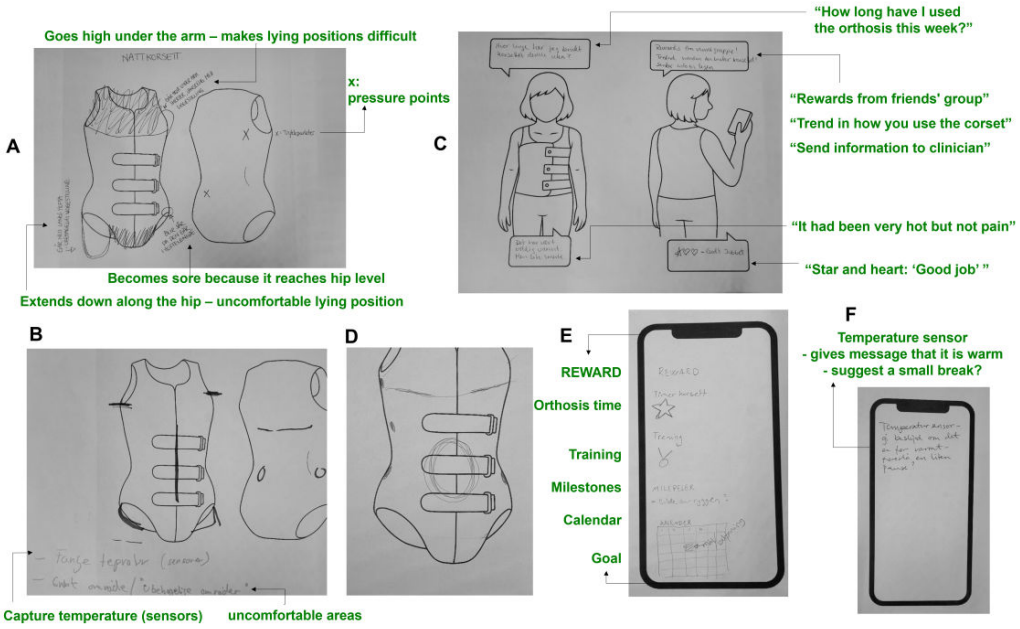



## Results From Illustrative Sketching

During the sketching activity, adolescents illustrated how they envisioned a smart orthosis communicating with them through a mobile app. The activity encouraged reflection on their treatment experiences and generated several meaningful suggestions from an adolescent perspective.

Figure 8 presents participant sketches from the workshop that illustrate envisioned assistive technology concepts. Explanatory labels and notes were added by the research team to aid interpretation. These sketches represent participants' ideas, preferences, and desired functionalities and should be regarded as conceptual design inputs rather than evidence of technical feasibility, implementation, or validated sensor performance. Figures 8A, 8B, and 8D primarily address RQ1 by depicting everyday challenges associated with orthosis use. Participants highlighted uncomfortable areas, particularly around the hips and orthotic straps, as common sources of discomfort and burden during treatment. The parent tried to communicate uncomfortable areas as reported from participants through an illustrative sketch in Figure 8A, the night orthosis, where *"x"* are pressure points. The participant described the uncomfortable pressure points in accompanying text. The participant described the reasons as follows: "Becomes sore because it reaches hip level," "Goes high under the arm—makes lying positions difficult," and finally "Extends down along the hip—uncomfortable lying position." One participant sketch highlighted specific areas of discomfort, particularly around the orthosis straps (Figure 8D), indicating a need for monitoring pressure points and uncomfortable regions.

**Figure 8.** Examples of illustrative sketches drawn by study participants.




The remaining illustrations addressed RQ2 by capturing adolescents' perspectives on future smart monitoring solutions. As illustrated in Figure 8C, participants expressed a desire for features that provided feedback on orthosis use (eg, "How long have I used the orthosis this week?"), visualizations of usage trends ("Trend in how you use the brace/corset"), motivational support ("Rewards from friends group" and positive reinforcement such as stars, hearts, and "Good job"), and mechanisms for sharing information with clinicians ("Send information to clinician"). Participants also highlighted the importance of symptom tracking, for example, distinguishing between discomfort and pain ("It had been very hot but not pain"). Participants frequently identified temperature sensing as a desirable feature (Figures 8B and 8F), suggesting sensors that could detect excessive warmth and provide heat-related alerts. Participants envisioned mobile apps as the primary interface for monitoring wear time, temperature, and orthosis use. Participants also highlighted motivational features, including rewards, positive feedback, progress tracking, exercise monitoring, and reminders (Figure 8E). These suggestions reflected common challenges associated with daily orthosis use, particularly thermal discomfort. The sketches complemented findings from the focus groups and Mentimeter polls by visually representing user-centered design requirements. The identified requirements were consistent with the major categories emerging across both study phases and may inform future smart monitoring system development. Older adolescents more often proposed practical sensor-based features, whereas younger participants focused on orthosis appearance and preferred design elements.

# Discussion

## Principal Findings

This study explored how adolescents with scoliosis and their parents perceive scoliosis monitoring and management to inform the development of a user-centered smart monitoring solution that supports orthosis management in everyday life. Through focus groups, Mentimeter polls, and sketching activities, participants emphasized the need for monitoring systems that support self-management, reduce uncertainty, and fit naturally into everyday life. Adolescents highlighted challenges related to heat, discomfort, orthosis fit, wear-time management, and maintaining daily activities during treatment. They envisioned monitoring systems that might provide meaningful feedback, for example, about duration of orthosis use, temperature, activity, and fit, while facilitating limited communication with clinicians and families.

The findings further suggest that future smart orthosis systems might need to integrate monitoring with positive, user-friendly gamified feedback. Participants favor motivational features such as rewards, progress visualization, automated reminders, and encouraging messages over systems perceived as controlling and judgmental. The convergence of findings across discussions, polls, and sketches strengthens the discussion and the credibility of adolescent-preferred design features that could form a foundation for building a prototype for further refinement.

## Monitoring and Feedback Needs in Everyday Orthosis Management

The findings indicate that adolescents perceive smart monitoring as more than a tool for measuring orthosis wear time. Participants described treatment as a complex process influenced by physical discomfort, social contexts, and day-to-day practical challenges. Heat, thermal discomfort,

orthosis fit, and maintaining activities emerged as recurring concerns across both study phases. These findings suggest that monitoring technologies should address issues that adolescents encounter during everyday orthosis use.

Adolescents emphasized the importance of reducing cognitive and emotional burdens associated with treatment. Both adolescents and parents described monitoring to reduce reliance on memory, assumptions, and repeated reminders. Parents particularly value the possibility of objective information to replace informal monitoring practices and reduce tension around orthosis wear. These findings suggest that smart monitoring systems may support shared understanding and communication between adolescents, families, and clinicians. Understanding wear duration is a primary design need for smart braces.

These findings align with previous literature highlighting the importance of family support, clinician involvement, and day-to-day treatment experiences in scoliosis management [26,27]. Orthosis treatment extends beyond clinical settings into everyday environments, where practical challenges such as taking breaks when it is too hot and having positive social interactions shape treatment decisions and adherence behaviors. Similarly, clinical decision-making and treatment success rely on continuous collaboration between clinicians, adolescents, and families [12]. This depends on what information the user wishes to share externally. Supporting these contexts may therefore be an important consideration in future monitoring solutions.

## User-Centered Design Requirements for Future Smart Monitoring Solutions

Participants identified several design requirements for future smart orthosis systems. Temperature monitoring was consistently highlighted across focus groups, polls, and sketches. Adolescents often associated orthosis use with heat and discomfort and viewed temperature sensing as a meaningful way to improve awareness of orthosis use and identify situations that may require adjustment or short breaks. Sketches frequently depicted mobile apps providing feedback regarding warmth, wear time, and treatment progress.

A Mentimeter poll indicated that both parents and adolescents prefer sensing modules on the orthosis rather than in undergarments. The preference for temperature monitoring is notable, given the established use of thermal sensors in scoliosis orthosis research and clinical practice. Clinics have used temperature-based monitoring systems placed on orthoses for over a decade. For example, Thermobrace has demonstrated the feasibility of objectively measuring orthosis wear and supporting adherence monitoring [28]. Studies suggested that smart monitoring may influence wearing behavior and treatment management [10]. Similarly, another popular temperature-based monitoring system demonstrated the feasibility of using sensors to monitor orthosis use in daily life [29]. These findings extend the literature by showing that adolescents perceive temperature monitoring as valuable not only for documenting wear time but also for improving comfort awareness and self-management.

Adolescents expressed interest in monitoring orthosis fit and activity levels. Discussions around orthosis fit were closely connected to discomfort, pressure points, and the practical challenges of adjusting orthosis use throughout the day. Several sketches highlighted uncomfortable areas around the hips and shoulder straps. These findings align with emerging studies on force and pressure monitoring in scoliosis orthoses. A pilot study from China demonstrated the feasibility of integrating thin-film force sensors into orthoses to support clinical monitoring [30]. More recently, researchers have explored combined temperature and force sensing approaches to distinguish orthosis wear, loosening, and removal during everyday use [31]. Studies evaluating pressure-adjustable orthoses [32] and pressure-sensing technologies [33,34] similarly suggest that monitoring orthosis wear quality may complement traditional adherence measures [15]. Wear quality, based on pressure and quantity or duration of wear, is gaining significance [35]. While these technologies are largely piloted or used in supervised clinical settings [30,36], adolescents in this study emphasized the importance of translating sensor outputs into user-understandable, actionable information. Activity monitoring was another desirable functionality. Participants wanted support for understanding how orthosis use influences participation in physical and daily activities. Previous studies have demonstrated the feasibility of combining motion and force sensors. The integration of these 2 sensor types enables the measurement of orthosis pressure during activities of daily living while simultaneously monitoring posture, movement patterns, and orthosis use in real-world environments [37]. Such approaches could provide adolescents with meaningful feedback on integrating treatment into daily life. However, the Mentimeter poll showed little interest in sharing data with an AI-based system.

Communication and data sharing emerged as another important design consideration. Most participants reported a willingness to share monitoring information with parents and clinicians. Sketches and poll responses suggested that participants viewed clinicians as trusted users of treatment data and valued opportunities for feedback between clinical appointments. However, willingness to share data with AI systems was considerably lower. AI-based systems were among the least preferred recipients of monitoring data. This finding highlights the importance of transparency, data governance, privacy protection, and trust when designing smart monitoring solutions, particularly within European health care contexts governed by General Data Protection Regulation requirements.

Motivational support was equally important. Adolescents prefer systems that encourage rather than judge. Positive messages, visual rewards, progress summaries, and gamified elements were seen as helpful ways to sustain engagement during long treatment periods. These findings suggest that successful systems should combine clinically meaningful sensor monitoring with motivational strategies that preserve autonomy and support positive treatment experiences.

An important observation was the difference between younger and older adolescents. While older participants more readily conceptualized sensor-based monitoring and practical smart functionalities, younger participants often focused on orthosis appearance and personalization. This finding suggests that future stakeholder workshops may benefit from low-fidelity prototypes or physical demonstrations when engaging younger users in designing advanced monitoring technologies.

## Triangulation of Data Sources and TPB Interpretation

Methodological triangulation combined focus groups, Mentimeter polls, and sketching activities. The study captured complementary perspectives on smart orthosis monitoring in Norway. Converging findings across data sources supported the refinement of emerging themes. These data sources provided a coherent understanding of adolescents' and parents' needs during scoliosis orthotic treatment and informed preliminary design recommendations for future smart orthosis monitoring systems.

To further interpret these findings, the inductively derived categories were examined through the lens of the TPB [18]. Categories related to social and environmental influences aligned with subjective norms, those concerning management of orthosis use and monitoring functions reflected perceived behavioral control, and categories describing experiences, preferences, motivations, and perceived benefits corresponded to attitudes. Consistent with TPB, these constructs helped interpret factors that may influence engagement with orthosis management and acceptance of future smart monitoring solutions. Importantly, we applied TPB to interpret the findings rather than to guide code or category development.

## Strengths

This study used a formative user requirements approach that actively involved adolescents and parents in identifying needs and design requirements for future smart orthosis systems. Methodological triangulation of focus groups, Mentimeter polls, and sketching activities enhanced the credibility of the findings, while the iterative design enabled participants to refine and validate ideas throughout the study. The hybrid workshop format also facilitated participation from adolescents across different regions of Norway.

## Limitations

Several limitations should be considered. The sample was small and context specific, limiting transferability beyond similar clinical and cultural settings. In addition, the limited phase 1 sample and anonymous data collection prevented assessment of participant overlap between study phases. Because Mentimeter responses were anonymous and not linked to participant identifiers, discrepancies between the number of registered participants and responses to individual questions could not be investigated retrospectively. This limits verification of response completeness and introduces minor uncertainty in the reported response counts. Therefore, the findings should be interpreted as formative user insights to support iterative user-centered design rather than as definitive requirements for all adolescents undergoing scoliosis orthosis treatment and their caregivers.

Limited participation by boys restricted exploration of potential gender differences. Findings were based on self-reported data and may have been influenced by recall bias, social desirability, varying interpretations of key concepts, and the inclusion of 1 parent representing a younger adolescent. Although the hybrid format improved accessibility, it may have affected participant interactions. Younger adolescents appeared to have greater difficulty conceptualizing advanced sensor-based monitoring features, which may have influenced the level of detail contributed during design activities. Finally, informal observations were not treated as empirical data, and the exploratory study design does not permit causal inferences. Future research should involve larger and more diverse samples and evaluate emerging solutions using prototypes.

## Conclusions

This study involved adolescents with scoliosis and their parents early in designing rehabilitation technologies. Participants viewed smart monitoring as more than a tool for measuring adherence. They emphasized the need for meaningful feedback, comfort management, motivation, communication, and support for everyday self-management. Across focus groups, polls, and sketches, temperature monitoring was frequently cited as an important functionality, followed by features related to orthosis fit, activity monitoring, data sharing, and positive reinforcement. The findings align with emerging evidence on temperature- and pressure-based monitoring technologies in scoliosis monitoring while highlighting the importance of translating technical capabilities into user-centered experiences. Future smart orthosis systems may benefit from not only collecting clinically relevant data but also providing understandable, supportive, and actionable feedback that promotes autonomy and trust. This formative user requirements study identified user priorities that may inform the future development of smart orthosis monitoring solutions. Future work should translate these requirements into low-fidelity prototypes and evaluate their usability, acceptability, and clinical relevance.

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## Generative AI Use

The authors acknowledge the use of generative AI tools for language editing and text restructuring. The generative AI-powered tools, such as Microsoft's Copilot and Grammarly, were used to restructure and reduce the word count of the text for clarity and to do the language correction of this paper, respectively. Microsoft's Copilot, supported by the dedicated university login, was used to translate sections of Norwegian text to English after anonymizing the data. The dedicated software login was used for the translation.

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## Data Availability

The datasets generated and analyzed during this study are not publicly available. The consent forms for the participants stated that the data would not be shared externally.

## Authors' Contributions

AM and PG contributed equally to investigation, data curation, resources, formal analysis, and writing the original draft. KS transcribed the audio recordings and translated them into English, and AM verified the translations. AM, PG, and TS conducted the coding. NP, AM, PG, MP, and KS conducted the stakeholder workshops with patients. MFK represented the scoliosis patient organization and supported recruitment and collaboration. PG, NP, MP, KS, TS, SA, and AM contributed to the conceptualization and design. PG, NP, and MBJ contributed to supervision and project administration. All authors contributed to the stakeholder workshops and to reviewing and editing and approved the final manuscript.

## Conflicts of Interest

None declared.

## Multimedia Appendix 1

Workshop protocol, representative codes, and Mentimeter poll findings.
[XLSX File (Microsoft Excel File), 4855 KB-Multimedia Appendix 1]

## Multimedia Appendix 2

Mentimeter responses per topic.
[DOCX File (Microsoft Word File), 16 KB-Multimedia Appendix 2]

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## Abbreviations

**RQ:** research question
**TPB:** theory of planned behavior


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