Exploring Opportunities to Improve Physical Activity in Individuals with Spinal Cord Injury Using Context-Aware Messaging

RITHIKA LAKSHMINARAYANAN, Northeastern University, USA
ALEXANDRA CANORI, Temple University, USA
ADITYA PONNADA, Northeastern University, USA
MELISSA NUNN, Temple University, USA
MARY SCHMIDT READ, Jefferson Health, USA
SHIVAYOGI V. HIREMATH, Temple University, USA
STEPHEN INTILLE, Northeastern University, USA

Spinal cord injury (SCI) affects the mobility of 250,000 people per year worldwide. Physical activity (PA) in individuals with SCI is positively associated with improved mental and physical health outcomes. Mobile technologies have been developed to motivate individuals with SCI to increase PA using activity tracking and real-time feedback. We conducted semi-structured interviews and participatory design sessions with 15 manual wheelchair users with SCI and eight of their family members/friends to investigate user impressions of future technologies that might use computer-mediated, sensor-triggered communication to motivate PA. We assessed barriers to PA and how context-aware communication could help overcome them. Participants with SCI expressed that PA tracking and communication technologies must be tailored to their specific needs. Further analysis revealed that context-aware messaging could help participants with SCI connect with others to initiate timely conversations about overcoming PA barriers, and to provide encouragement to meet their PA goals. We discuss opportunities to empower individuals with SCI with regards to PA using tailored, context-aware communication.

CCS Concepts: • **Human-centered computing** → **Accessibility;** *Accessibility design and evaluation methods*

Additional Key Words and Phrases: spinal cord injury, physical activity, context-aware communication

ACM Reference format:

Rithika Lakshminarayanan, Alexandra Canori, Aditya Ponnada, Melissa Nunn, Mary Schmidt Read, Shivayogi V. Hiremath, Stephen Intille. 2022. Exploring Opportunities to Improve Physical Activity in Individuals with Spinal Cord Injury Using Context-Aware Messaging. In *Proceedings of the ACM on Human-Computer Interaction,* Vol. 6, CSCW2, Article 515 (November 2022), 27 pages, https://doi.org/10.1145/3555628

Author's email addresses: Rithika Lakshminarayanan, lakshminarayanan.r@northeastern.edu; Alexandra Canori, alexandra.canori@temple.edu; Aditya Ponnada, ponnada.a@northeastern.edu; Melissa Nunn, melissa.nunn50@gmail.com; Mary Schmidt Read, mary.schmidt@jefferson.edu; Shivayogi V. Hiremath, shiv.hiremath@temple.edu; Stephen Intille, s.intille@northeastern.edu

2573-0142/2022/November – Article 515 $15.00

https://doi.org/10.1145/3555628

1 INTRODUCTION

Spinal cord injury (SCI) is a debilitating condition that limits mobility and autonomy of those affected. According to the World Health Organization, between 250,000 and 500,000 people are diagnosed with SCI around the world every year [3]. The estimated number of people living with SCI in the United States (US) alone is approximately 296,000, with about 17,900 new cases being added every year [4]. Nearly 60% of individuals with SCI start using wheelchairs within a year post-injury due to the severity of injury [1]. The treatment costs associated with this type of injury at the individual level exceed $1.5M over the lifetime of an average 25-year-old in the US [4].

Prior studies in individuals with SCI have found that higher levels of PA were associated with lower levels of fatigue, pain, and depression [59, 83]. Given the benefits of PA, prior work has explored how regular tracking and feedback on accurate estimates of PA help improve everyday PA levels in the general population [19]. Self-report is one such method that has been used to gather information on PA levels of individuals with SCI. However, self-report may introduce response burden, recall bias, and social acceptability bias [24, 90, 92]. To support a system that improves accuracy of measured PA, novel smartphone-based interventions that make use of less burdensome passive activity measurement techniques are being evaluated [11, 31, 42]. Such systems could improve health-related outcomes in individuals with disabilities with minimal user burden. In particular, just-in-time adaptive intervention (JITAI) systems that automatically detect PA from wearable sensors and provide near-real-time feedback to promote health and wellness are gaining traction and might support individuals with SCI [55].

In contrast to the general population, individuals with SCI who use wheelchairs for mobility must overcome significant physiological and environmental barriers to participate in PA in their communities. Secondary conditions associated with SCI, including pain, fatigue, depression, and weight gain result in them having lower levels of PA [24, 73, 83]. Moreover, they face additional challenges in being physically active such as accessibility of spaces [69, 70], lack of access to exercise equipment [72], and lack of information regarding safe PA [69, 81]. Thus, JITAIs that target the general population may not be suitable for individuals with disabilities without significant design modifications, that not only account for the constraints faced because of the SCI, but also their motivations to be physically active (e.g., health benefits, appearance) [14, 15]. Peer support and mentorship [17, 21, 23, 33] can create a sense of belonging [35, 81] and a sense of community [65, 83] through the exchange of social support (e.g., encouragement, advice) to increase PA in individuals with SCI. To our knowledge, there is no existing literature about technology-mediated just-in-time communication to provide social support and increase PA levels. To address this gap and to ensure that individuals with SCI who use manual wheelchairs benefit from the emerging JITAI technologies, we conducted a participatory design-based study exploring the space of JITAI-based communication for individuals with SCI. We recruited 15 individuals with SCI and eight of their family members/friends and qualitatively explored the following research questions:

- **RQ1:** How might novel communication tools be used to help individuals with SCI overcome some of their barriers to engaging in PA?
- **RQ2:** What role could timely encouragement and support from peers and supporters play when developing systems intended to promote PA among individuals with SCI who use wheelchairs?

Interpersonal communication technologies help individuals connect with one another. In this work, we explore how the combination of sensing with messaging might help facilitate timely and meaningful communication to empower individuals with SCI to improve their PA levels. We observed that social and communication applications are among the most frequently used applications on mobile phones [40], with people turning more towards these technologies during the COVID-19 pandemic to keep themselves connected [46, 74, 93]. The success of previous SMS-based (Short Messaging Service) interventions in promoting health behavior change such as weight loss [78], smoking cessation [29], and PA promotion [49] led us to explore designs for a messaging application that would facilitate the exchange of social support for PA while preserving the aspects of texting applications that mobile phone users are familiar with and use frequently. Hawkins et al. recommend tailoring content to the target audience to increase efficacy of messaging for communication related to health [30]. JITAIs focus on in-the-moment content delivery, a key component in giving users timely support needed to change health behaviors [55]. This led us to design features that combine the power of timely content delivery with that of content tailoring by enabling social supporters (friends and family) to author content best suited to participants, and motivate PA.

Our participants highlighted the importance of social interaction and communication on their PA levels and generally expressed that a context-aware messaging application might be appropriate to provide social support in certain situations. Participants reported that there was a lack of personal fitness tracking applications tailored to them and that they would use a context-aware communication method to initiate PA-based conversations with friends and family in certain situations where they would find it difficult to type out messages due to time or physical function constraints. Based on our interviews, we describe directions for how just-in-time digital social support might be used to support under-served populations, discussing how a context-aware messaging application might best attempt to increase PA levels in individuals with SCI.

The key contributions of this paper are:

- Exploring how computer mediated just-in-time social support can help promote PA in individuals with SCI
- Understanding limitations of current PA tracking technologies used by participants and designing user experiences that focus on the nuances of PA for persons with SCI

2 RELATED WORK

This work is motivated by prior work on barriers to PA for persons with SCI, technological and behavioral interventions to increase PA in individuals who use wheelchairs, social support in health contexts, and JITAIs and context-aware interventions designed to improve health behaviors in the general populace.

2.1 Barriers to PA in Individuals with SCI

Prior research has identified multiple factors that influence PA levels in individuals with SCI. In this section, factors will refer to aspects that can both be facilitators or barriers to PA. Subjective well-being (SWB) is one such factor defined as a person's perceived happiness and satisfaction with life [36]. Research studies have found that lower levels of SWB, including depression, lack of self-confidence, and embarrassment, were barriers to PA [45, 52, 77]. Environmental factors (factors outside of one's control) such as weather, available transportation to facilities, inadequate finances, lack of personal and communal resources, accessibility, and availability of resources have been identified as barriers to PA in prior studies [35, 50, 68-71, 81]. In addition, participants across multiple studies mentioned physical impairments due to SCI as barriers to exercise. Fatigue, loss of bodily strength, and other secondary health conditions contribute to low PA levels [28, 81, 88]. In fact, for some people, partaking in PA resulted in further pain or injuries [47]. Moreover, information on safe PA guidelines for individuals with SCI was reportedly difficult to find for many people [35, 45, 52]. Further, some individuals mentioned not being able to find enough time or energy to be physically active and felt that the perceived benefit did not justify the efforts [47, 62].

Beyond individual-level factors, social support also affects PA levels. Social support in this case consists of emotional support in terms of guidance and advice, and physical support in terms of assistance and providing transport [47]. Lack of assistance from others resulted in lower PA levels because individuals with SCI often depend on assistance to reach facilities or use equipment [35, 81]. Social support networks consisted of family, friends, disability groups, and fitness centers [45, 52, 65]. People with SCI reported that engaging in PA with disability groups allowed them to learn from others with similar injuries and explore possibilities for health and fitness, leading to greater independence in their daily life [17]. Individuals with SCI who receive peer support and mentorship had better outcomes post-injury, including higher participation in self-care, engagement in rehabilitation, confidence in their abilities, and lower hospital readmissions [17, 21, 65]. In this work, we will explore barriers to PA from a technological support perspective in addition to the factors listed above.

2.2 Interventions to Increase PA Levels in Individuals who use Wheelchairs

Technology-driven behavioral interventions to increase PA have been tested with individuals who use wheelchairs with varying degrees of success. For instance, the HABITS randomized controlled trial (RCT) used a structured self-management intervention to promote PA in individuals with SCI [43]. Sixty-four participants were randomized either to a 16-week self-management intervention consisting of group meetings, individual counseling, and a booklet on how to stay fit with SCI, or to a control group that only received information about active lifestyle by one group meeting and the booklet. After 16 weeks, the study found no statistically significant differences between these groups in attitudes towards a physically active lifestyle, perceived behavioral control, or stages of change in the transtheoretical model (TTM) of behavior change [20]. Bakkum et al. [9] conducted a randomized controlled trial with 20 participants over 16 weeks to compare the effects of hybrid cycling (voluntary arm exercise combined with functional electrical stimulation (FES)-induced leg exercise) and handcycling on PA levels in individuals with SCI. At the end of the study, the researchers found that hybrid cycling and handcycling had similar effects on PA levels.

In another study, Nooijen et al. [60] evaluated the addition of a behavioral intervention to rehabilitation techniques to promote PA levels in people with SCI. They conducted an RCT with 45 participants. While all participants received regular rehabilitation, including handcycle training, only the experimental group was exposed to the behavioral intervention. The study found that the behavioral intervention significantly increased wheeled PA (overall between-group difference was 21 min per day, 95% CI: 8 to 35 min). There was no statistically significant difference in sedentary times across both groups. Self-reported PA levels increased in the experimental group.

In a manual wheelchair propulsion intervention for persons with multiple sclerosis, PA of 14 participants were observed were observed over a three-month period [67]. Participants were randomly assigned to the intervention group or the control group. Participants in the intervention group received custom-fit, ultralightweight manual wheelchairs with propulsion/skills training, followed by 3 months of at-home use with the custom ultralightweight wheelchair and weekly phone calls to deliver support through a multifactorial intervention. The control group participants received no training and used their own wheelchairs at home during this period. The intervention group demonstrated increased strength (P=.008) and a trend toward less fatigue (P=.068), both with large effect sizes (d>0.8), as well as reduced application of braking torque during propulsion (P=.003) with a moderate/large effect size (d=.73), compared with the control group.

While there have been multiple studies conducted on accurately measuring PA levels in wheelchair-based activities using sensors [10, 18, 48, 91], sensor-driven PA interventions are still not common with the SCI population. With our proposed application, we plan to use advances in sensing to support a PA intervention in individuals with SCI.

2.3 Social support in health contexts

Social support can be defined as 'an exchange of resources between individuals in a social network' [79]. Research has shown that social support is related to better physical health, lower pain, effective coping, better adjustment to disability, and higher life-satisfaction, and quality of life in individuals with SCI [38]. Social support in group and community settings has been shown to improve health outcomes in both the general population and individuals with SCI [21, 54].

The exchange of peer support and mentorship in communities of individuals with spinal cord injury has led to higher levels of physical activity and improved health outcomes [17, 21, 23, 33]. The exchange of social support (e.g., encouragement, advice) can create a sense of belonging [35, 81] and a sense of community [65, 83] to motivate PA. van den Akker et al. [89] conducted focus groups with 25 participants with SCI and 11 rehabilitation professionals to study the determinants of PA in wheelchair users with SCI or lower limb amputation. They found that level of social support was one of the environmental determinants of PA levels, with higher levels of perceived social support leading to higher PA levels. Individuals with SCI who receive peer support and mentorship had better outcomes post-injury, including higher participation in self-care, engagement in rehabilitation, confidence in their abilities, and lower hospital readmissions [17, 21, 65]. This may be because the lack of social support from friends and family may make it harder for individuals with SCI to travel, access facilities, and receive the physical support that they may need to perform everyday tasks like reaching for high shelves.

The evidence of the positive effects of social support on PA levels from numerous studies and systematic literature reviews led us to explore the design of a system that enables easy exchange of social support. Because it is not always possible for the caretaker or peer supporter to be physically present to provide the social support, we decided to explore digital means of enabling social connections.

2.4 JITAIs and Context-aware Interventions for Behavior Change

Just-in-time adaptive interventions (JITAIs) make decisions on when and how to deliver an intervention based on a user's state or context to enable positive health behavior change. For instance, QSense [56] is a mobile phone application for tobacco smoking cessation that senses an individual's location and delivers behavioral support (coping strategies) triggered by and tailored to contextual features to prevent smoking lapse during a quit attempt. The app administers an ecological momentary assessment (EMA) every time an individual reports smoking to identify associated context (mood, stress, urge, current locations). After an initial data collection period, the app identifies high risk locations and situations and delivers a support message with coping strategies to the user via notification when the user is in such a situation. The researchers found that while self-reporting is a feasible way to train a smoking cessation app, there was often underreporting. The geofence triggered location support was, however, regarded positively by participants. A-CHESS [27], PHIT for duty [41] and SARA [66] also use JITAIs delivered via mobile phones to help people with an alcohol and/or drug addiction. All these apps use self-report to collect data from participants, like QSense; accurate passive sensing permits reduced reliance on self-report.

HeartSteps [42] is a JITAI mobile app that promotes walking using contextually-tailored suggestions. The application interacts with users through push notifications, delivering either a suggestion to go for a walk, or a suggestion to engage in anti-sedentary behavior (stand up, stretch, etc.). Users can specify when they wish to receive these suggestions and the app will deliver them at the specified time if the user is not already busy (walking, driving or offline). A micro-randomized trial of HeartSteps found that the context-tailored walking suggestions increased participant average step counts by 24% over all study days. PHIRE [31] was an Android application developed as part of a research study that used accelerometer data from a wrist worn smartwatch to classify and estimate PA levels in wheelchair users with SCI. Based on activity levels, the app delivered just-in-time feedback through push notifications on the watch to encourage users to meet their PA goals. The app was evaluated with 20 participants over three phases, with the first phase being used to collect baseline activity levels. Results showed that 11 participants had higher light- and/or moderate-intensity PA when feedback on PA was delivered using a JITAI, as compared to the baseline. We extend some of the ideas presented in HeartSteps [42] and PHIRE [31] to explore design directions for a just-in-time delivery of human-authored messages from friends and family members – to enhance social support.

3 METHOD

The work presented in this manuscript results from formative work in an ongoing participatory design process, the goal of which is to iteratively develop and test prototype JITAI systems sensitive to the individual and interpersonal needs of individuals with SCI and their support networks (e.g., family members, friends, sports teams for individuals with SCI). We focused on assessing the needs of these participants and engaging them in the co-design process of the application. We conducted semi-structured interviews and participatory design sessions remotely over a video conferencing software with each participant and one friend or family member of theirs (henceforth referred to as supporter), if available, to understand the challenges they face in engaging in PA and how a mobile health (mHealth) application might help them overcome some of those challenges. Each participant (and their supporter, if available) participated in a total of five sessions — an initial session where we gathered demographic and injury-related information, two interview sessions and two storyboarding sessions (Fig. 1). The interview sessions helped us design features and storylines for the storyboarding sessions. Participants contributed design ideas during these sessions for features we could add to improve the user experience. We also iteratively refined designs between participants and between sessions based on their feedback from the sessions.

The time between sessions varied for participants and was based on their availability. Each session was scheduled approximately one week apart, however shorter durations of 2-3 days were permitted for participants who expressed need for completing them sooner due to upcoming schedule conflicts (i.e., planned surgical procedures or travelling), and longer durations of up to three weeks between sessions were common for participants who requested postponing due to illness, work obligations, or other conflicts in schedule. The allotted time between sessions allowed us time to refine our storyboarding designs based on feedback from the interview sessions. Four participants were unable to continue after Session 1 due to health reasons. Content was created for each session in consultation with the SCI consumer advocate on our research team, henceforth referred to as our *research partner,* who is a co-author on this paper. Our research partner has been living with SCI for 13 years. She has been a peer mentor for the past nine years at Philadelphia Peer Mentorship Program at Magee Rehabilitation Hospital that provides support to others with SCI during their recovery and reintegration in the community.

The decision to include friends and family members as stakeholders in the design process was made because they will also be users of our proposed application, writing messages to provide just-in-time support to individuals with SCI. Their perspective helped us understand the different kinds of support the mobile application could enable users to provide. In the designs we presented, communication and support were always two-way, and balanced, assuming that individuals with SCI would not only receive support from the friend or family member, but also provide support to the friend or family member. This balanced design could create a more equitable exchange of support, reducing the chances of a potential power differential between the two parties. This led us to explore a design where both parties would be able to exchange encouragement and support, without one party feeling like they were being told what to do by the other. Thus, the system might feel less stigmatizing to the persons with SCI. We aimed to create designs for a PA-promotion application, tailoring the user experience to individuals with SCI, with the goal of providing just-in-time social support. In the past, SMS-based interventions have been used to successfully increase PA levels by providing informational and social support [49], without the need for supporters to be physically present. The combination of the familiarity and popularity of text messaging applications with participants, and the success of SMS-based mHealth interventions in the past in promoting PA led us to focus on messaging for this study. We explored the possibility of asynchronous communication to allow senders to write supportive messages when they had time and to have the messages be delivered “just-in-time" when a recipient needed support, believing this might enhance the value of messaging already known to be impactful. With the input of the participants and their supporters, we generated preliminary designs for tasks that the application could help facilitate.

In later sessions, we used elements from the storyboarding method, to set the context and provide a storyline [86] for presenting a set of low-fidelity prototypes [76]. We developed these prototypes showing two hypothetical individuals exchanging messages. Our aim was to gather input from participants and identify potential design opportunities for a communication app that could offer timely social support to participants. The study was approved by the both universities' IRB.

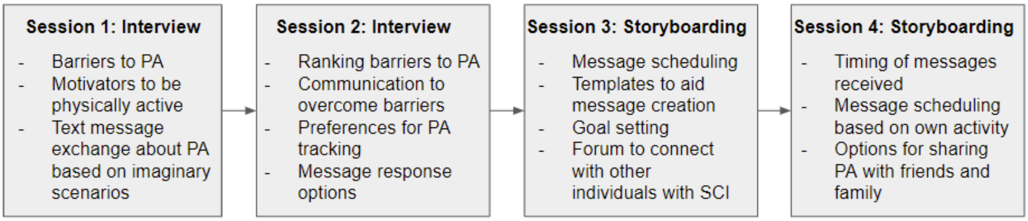


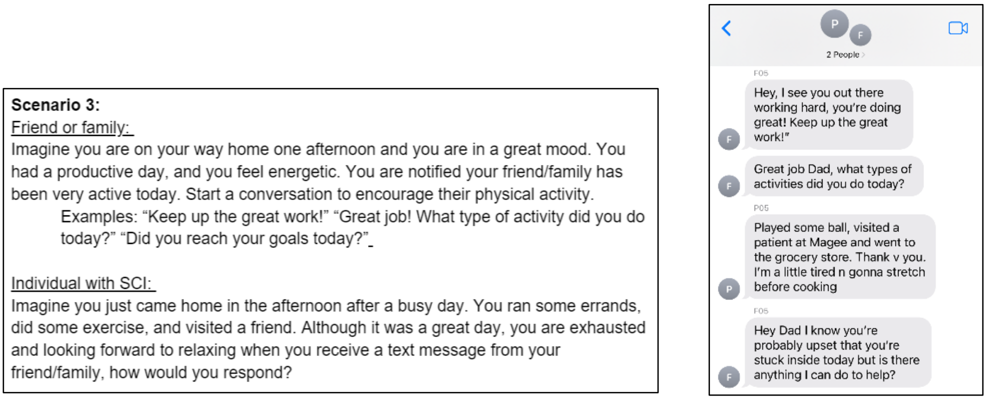
Fig. 1. Summary of activities conducted during sessions in the study. The initial information gathering session was conducted before Session 1.

3.1 Participant Recruitment and Procedures

Participants were recruited from a local rehabilitation hospital; the hospital sent flyers to its two outpatient departments describing the study, and we contacted previous study participants via email. Individuals with SCI were eligible to participate if they: (1) were between 18 and 75 years of age, (2) had history of traumatic or non-traumatic SCI, (3) used a manual wheelchair as their primary means of mobility (>80% of time), (4) were interested in increasing their PA, and (5) could use a smartphone and a smartwatch independently. Participants with SCI were excluded if they: (1) had health conditions that made PA medically contraindicated or unsafe, (2) had a history of traumatic brain injury, or (3) were currently pregnant. Friends and family members of individuals with SCI were recruited in conjunction with participants with SCI. Friends and family members were eligible to participate if they: (1) were at least 18 years old, and (2) were able to use a smartphone and smartwatch independently. The exclusion criterion for friends and family members was a health condition that medically restricted PA. Participants were recruited as a dyad with their friend or family member, or individually if they did not have a friend or family member to join them in this study. All participants provided informed consent and were compensated $20 per session for their time for up to five sessions.

3.2 Initial meeting and Phase 1: Interviews

During the initial meeting we collected demographic data from participants. In the next two meetings (Sessions 1 and 2) we gathered general information about barriers and motivations for PA, and the kinds of messages participants would send to each other in various scenarios. Interviews were conducted with both the individual with SCI and the participant's friend/family member, together. However, recruitment was expanded to include individual participants with SCI by themselves to allow enrollment of individuals who did not have a friend or family member willing to participate with them.



Scenario 3:

Friend or family:

Imagine you are on your way home one afternoon and you are in a great mood. You had a productive day, and you feel energetic. You are notified your friend/family has been very active today. Start a conversation to encourage their physical activity.

> Examples: "Keep up the great work!" "Great job! What type of activity did you do today?" "Did you reach your goals today?"

Individual with SCI:

Imagine you just came home in the afternoon after a busy day. You ran some errands, did some exercise, and visited a friend. Although it was a great day, you are exhausted and looking forward to relaxing when you receive a text message from your friend/family, how would you respond?

F05

Hey, I see you out there working hard, you're doing great! Keep up the great work!"

Great job Dad, what types of activities did you do today?

P05

Played some ball, visited a patient at Magee and went to the grocery store. Thank v you. I'm a little tired n gonna stretch before cooking

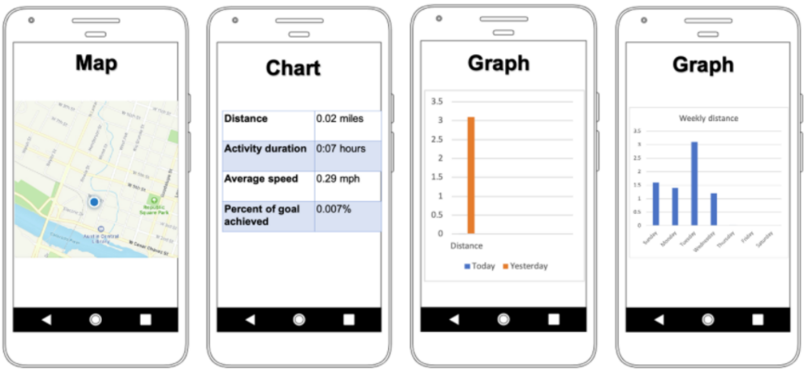
F05

Hey Dad I know you're probably upset that you're stuck inside today but is there anything I can do to help?

Fig. 2. (a) A scenario that participants were shown in interviews in Session 1. Participants were sent the part of the scenario relevant to them (individual with SCI or friend/family); (b) Part of a text message exchange between participants for Scenario 3 in Session 1.

3.2.1 Session 1: Barriers and motivators to PA. We conducted semi-structured interviews with the participant with SCI and their supporter (if present) to discuss their routines related to PA. Participants were asked about (1) what barriers exist to PA; (2) what motivates them to be physically active; and (3) the types of communication participants had with others regarding their PA. Towards the end of the session, participants were presented with scenarios that might occur in one's daily life (Fig. 2) and asked to exchange messages based on them through their phone's SMS (Short Messaging Service), using the concept of a 'compound prototype' [5]. A compound prototype allows researchers to present users with the experience of using the final product without fully implementing it by combining what the user interface might look like and a computational implementation running on a separate device. The reason for using the phone as part of the prototype for the text message exchange was to simulate the short bursts of computer-mediated communication that people generally engage in – switching quickly between tasks – that would not have been possible to accurately simulate in a low-fidelity prototype. We created five scenarios – with input from our research partner for authenticity – to gauge how participants would react when they (a) received a message based on PA inaccurately detected by their device; and (b) received an encouraging message when they performed some PA. When we had both the individual with SCI and the friend/family member, they were both given different roles in the five scenarios and asked to text message each other. Typical message exchange sessions consisted of 6-7 messages per scenario on average. In the nine cases when we only had one participant in a session, we did not conduct the message exchange activity. A text message group chat between the individual with SCI, the friend or family member, and a researcher from our team was created. The researcher was a silent observer, not replying to any of the messages exchanged in the group chat but able to see the messages exchanged between participants. All content of exchanged text message conversations was copied into our transcripts for analysis.

3.2.2 Session 2: PA tracking. In Session 2, participants were asked to (1) rank common barriers mentioned in Session 1, based on their interference with PA from least significant to most significant; (2) discuss how support exchanged over text messaging or a user forum could help overcome them; (3) indicate their preferences for PA tracking; and (4) choose how they would respond to messages in scenarios we created based on daily life occurrences. We asked participants how they would like to track their activity goals, showing them four different tracking options (Fig. 3) and asking participants to reflect on those they felt would be most motivating to them. These options were chosen based on activity tracking options commonly used in commercially available PA tracking applications such as Strava, Google Fit, and Apple fitness.



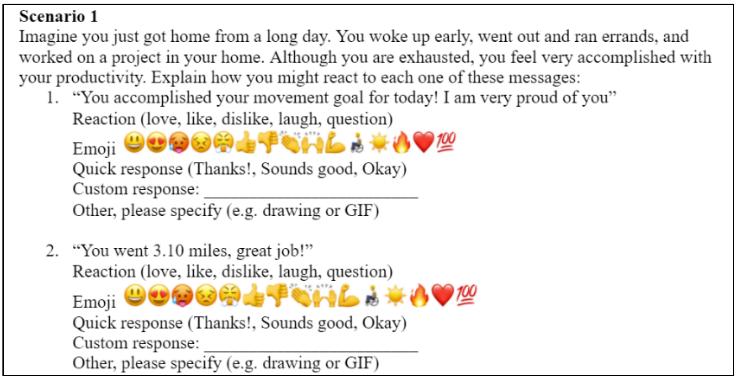
Distance	0.02 miles
Activity duration	0:07 hours
Average speed	0.29 mph
Percent of goal achieved	0.007%

Fig. 3. In Session 2, four different goal tracking options were shown, and participants were asked to indicate their preference. From left to right: (a) A map showing the path covered; (b) A chart showing summary details of PA; (c) A graph comparing the previous day's activity levels with the current day's activity levels; and (d) A graph showing distance covered while performing PA over a week.

Finally, we presented participants with examples of messages they might receive based on a given scenario, and they were asked how they would respond to those messages (Fig. 4). In this session, they only had to choose how they would respond to message contents that we showed them, instead of sending texts, as some did in Session 1. They had the option of responding with free text, emojis, reactions, pre-populated responses, or other multimedia content. The purpose here was to understand how participants would react to different kinds of congratulatory messages.

3.3 Phase 2: Storyboarding

We used the next two meetings (Sessions 3 and 4) to gather participant feedback about features of the app that were designed based on data collected from multiple participants over the previous sessions. We iteratively refined design ideas based on participant feedback to present to future participants. We also added designs ideas for new features that participants designed in the sessions. For these sessions we used storyboarding [62] to present participants with character-based storylines and set the stage for a message exchange between two characters using low-fidelity prototypes. Participants were asked to react to these stories based on their understanding of the prototypes and the storyline.



Scenario 1

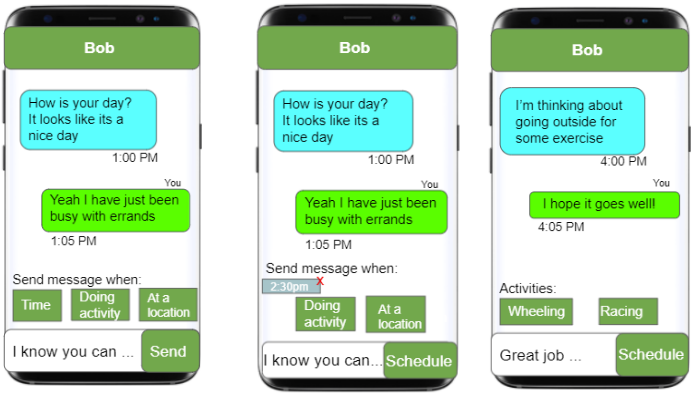
Imagine you just got home from a long day. You woke up early, went out and ran errands, and worked on a project in your home. Although you are exhausted, you feel very accomplished with your productivity. Explain how you might react to each one of these messages:

1. "You accomplished your movement goal for today! I am very proud of you"
   Reaction (love, like, dislike, laugh, question)
   Emoji 😃😍🥵😣😤👍👎👏🙌💪🧑‍🦽☀️🔥❤️💯
   Quick response (Thanks!, Sounds good, Okay)
   Custom response: ____________________
   Other, please specify (e.g. drawing or GIF)

2. "You went 3.10 miles, great job!"
   Reaction (love, like, dislike, laugh, question)
   Emoji 😃😍🥵😣😤👍👎👏🙌💪🧑‍🦽☀️🔥❤️💯
   Quick response (Thanks!, Sounds good, Okay)
   Custom response: ____________________
   Other, please specify (e.g. drawing or GIF)

Fig. 4. Examples of messages and their response options shown to participants during Session 2.

3.3.1 Session 3: Message scheduling and templates. From information we gathered about PA barriers and motivators in the first two sessions, we developed concept screens for a mobile based messaging application that could allow users to schedule messages to be sent when others need support. These concept screens were created to be like standard text messaging applications, so that participants would be able to use the proposed application intuitively. We added buttons at the bottom to allow participants to schedule messages to be sent in the future based on events suggested in the interview sessions. In Session 3, we showed participants concept screens demonstrating how the message scheduling features might work (Fig. 5), how templates might be used to aid in composing message (Fig. 6b), how goal setting might be used, and how messaging might enable individuals with SCI to connect with each other through a forum on the application to ask for, or to offer, help. Templates were created by the research team based on messages from previous sessions and with input from our research partner. For each of the features, we gave them scenarios to work with and asked them for their thoughts and feedback.



Bob

How is your day? It looks like its a nice day
1:00 PM

You
Yeah I have just been busy with errands
1:05 PM

Send message when:

I know you can ...

Bob

How is your day? It looks like its a nice day
1:00 PM

You
Yeah I have just been busy with errands
1:05 PM

Send message when:
2:30pm

I know you can...

Bob

I'm thinking about going outside for some exercise
4:00 PM

You
I hope it goes well!
4:05 PM

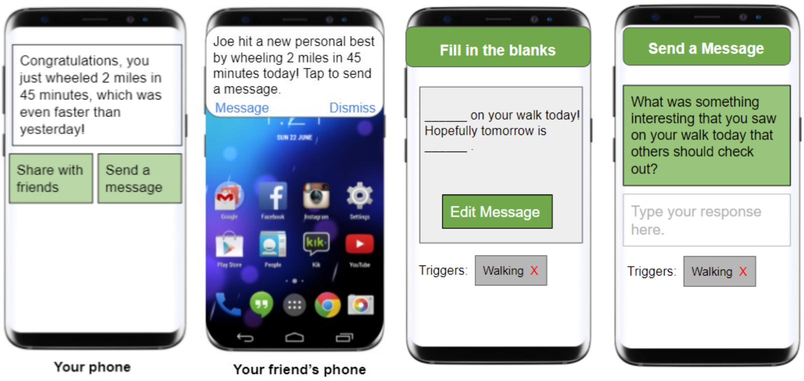
Activities:

Great job ...

Fig. 5. Prototype screens showing the message scheduling feature.

3.3.2 Session 4: Message scheduling and PA sharing options. Based on feedback we received from Session 3, we refined some of our designs and added concept screens for features requested by participants for Session 4. The features for which we developed low-fidelity prototypes included:

(1) preferences for when and how participants would like to receive notifications for context-aware messages; (2) methods to share PA updates with friends and family (Fig. 6a); and (3) a way to schedule message delivery based on one's own activity. Prototypes (1) and (2) were designed to explore differences in personal preferences for timing and method of notification, and automatic sharing of PA goal tracking with friends and family. Prototype (3) was suggested and designed by participants in Session 3, to give participants the ability to initiate conversation automatically based on a detected activity, instead of only being able to receive scheduled messages based on their activity. In this session, like Session 3, participants were shown storylines with low-fidelity prototypes of the features mentioned above and asked to react to the stories.



Congratulations, you just wheeled 2 miles in 45 minutes, which was even faster than yesterday!

Joe hit a new personal best by wheeling 2 miles in 45 minutes today! Tap to send a message.

______ on your walk today! Hopefully tomorrow is ______ .

What was something interesting that you saw on your walk today that others should check out?

Type your response here.

(a) (b)

Fig. 6. (a) One of the activity-sharing storyboards participants were shown in Session 4; (b) Templates to aid message creation used in Session 3.

3.4 Analysis

Audio from 87 interview sessions were recorded and transcribed using Zoom; a member of our research team then reviewed the audio and transcripts for accuracy and corrected errors as needed. We had a total of 42.7 hours of audio, with a mean interview length of 29.4 minutes. Six interviews in Session 1 involved the exchange of text messages in a group conversation. These messages were added to the relevant transcripts. We conducted a reflexive thematic analysis [12] of the transcripts from the interviews guided by our research questions. In our analysis, we used elements from grounded theory including constant comparisons, axial and selective coding, and memo writing [82]. Two independent researchers coded the transcripts separately using Quirkos (version 2.4.1), labeling emergent phenomena to arrive at a codebook by consensus. We grouped similar codes together to identify the major themes that emerged. The researchers then independently applied these selective codes to the transcripts to identify emerging themes. The researchers met throughout the coding process to merge codes and update the codebook if needed.

As part of our participatory design process, we worked directly with our research partner. The research partner reviewed focus group material and provided suggestions on how to make structured interview questions and scenarios most applicable to individuals with SCI. Suggestions were diverse and ranged from advising that focus group meetings have allotted time for participant rest breaks to making suggestions about the participatory design materials (e.g., replacing phrases such as 'go for a walk' to 'go for a roll.'). Additionally, we spoke with a clinician with over 30 years of experience working with individuals with SCI, who highlighted the barriers that individuals with SCI face in the community including but not limited to mobility issues and lack of accessible environments.

3.5 Participant Overview

The study had 23 participants in total - 15 individuals with SCI and eight friends or family members. The average age of participants with SCI was 47.4 years (SD = 13.5 years, range: 28-71 years). The average age of the friend/family members was 45.3 years (SD = 14.4 years, range: 22-62 years). Other demographic details are shown in Table 1. After contacting about 40 eligible participants who indicated that they did not have a friend or family member willing or able to enroll in the study with them, we changed our recruitment procedures to allow individuals with SCI to enroll on their own without a friend or family member.

Table 1. Summary of participant demographics

Variable	Participants with SCI	Friends/Family members
Sex	13 male, 2 female	2 male, 6 female
Gender	12 men, 2 women, 1 non-binary	2 men, 6 women
Race	12 white, 2 Black, 1 Asian/white	5 white, 2 Black, 1 Asian/white
Age (years)	47.4 mean, 13.5 SD, 28-71 range	45.3 mean, 14.4 SD, 22-62 range
Years since injury	17.2 mean, 14.8 SD, 0-45 range	N/A
Level of injury	3 tetraplegia, 12 paraplegia	N/A
Completeness of injury	11 complete, 4 incomplete	N/A
Relationship to individual with SCI	N/A	4 spouse/significant other, 1 father, 1 daughter, 1 sister, 1 friend

4 FINDINGS

The analysis identified the underlying themes of: (1) PA as a means of social interaction; (2) communication to overcome barriers to PA; (3) the role of context in messaging; and (4) opportunities where a context-aware messaging application could help facilitate higher levels of PA in individuals with SCI. Because many of our interviews involved both the participant with SCI and their friend/family member, henceforth we will use the prefix P in combination with a number to refer to the individual with SCI and the prefix F in combination with a number to refer to the friend/family member (e.g., F3 refers to friend or family member to P3 with SCI). Friends and family members were included in the interview process as they are sources of support for individuals with SCI and we wanted to include them in the design process as well. The barriers that participants mentioned have been summarized in Table 2. We will review some of the identified barriers, and then discuss if and how they might impact the interface design in this section. The findings have been structured into subsections based on the phase of the study they originated from (Phase 1 or 2).

Table 2. Barriers to PA mentioned by participants with SCI in our interviews

Barriers identified in prior work that were mentioned in interviews	New barriers identified from interviews
• Accessibility, cost of equipment, availability of resources • Needing assistance, lack of social support • Mood, depression, pain, fatigue • Weather • Time and effort involved	• Lack of tailored, PA-focused forums to connect with similar people • Lack of personal fitness tracking devices/applications tailored to wheelchair-based activities

4.1 Phase 1: Interviews to understand motivators and barriers to PA

Sessions 1 and 2 focused on understanding the motivators and barriers individuals with SCI faced when they tried to engage in PA. These interview sessions also helped us understand the role of friends and family members in motivating PA in individuals with SCI.

4.1.1 PA as a means for social interaction. PA was described as a means to **facilitate social interaction** and make meaningful connections. Participants mentioned engaging in different kinds of activities with friends and/or family, including wheelchair basketball, wheelchair tennis, adaptive handcycling, kayaking, and rowing. Four participants mentioned that they were more likely to be physically active if they were out with others or participating in group activities. P2, talking about her experiences explained: *"[...] friends have taken me kayaking... so it doesn't take much of a suggestion, I'm all in, so that kind of stuff is great if somebody says, 'well, hey, let's go for a hike.' We were just out on Saturday and went to a park. So yeah, definitely all in for any activity somebody starts to say go."*

P7 mentioned an adaptive handcycling gym that he visited frequently before the COVID-19 pandemic, saying, *"[...] they open it up and they let everyone come and use the hand cycles or the special bicycles for different disabled folks, and they open up for spring and summer and into the fall, but it was closed during 2020 because of the virus."* This was a place where P7 would meet others with similar disabilities and use otherwise expensive equipment to exercise for a nominal fee. Being able to share the workout experience with others – both individuals from the general population and individuals who use wheelchairs – was a motivator to be physically active.

We observed that **social accountability** appears to be a motivator to be physically active in this population, just as in the general population. To distinguish social accountability from the general notion of feeling connected to others, we define social accountability as the social responsibility one feels to another person. Social accountability was especially important for participants that had other people relying on them – e.g., sports teams, family members, or other wheelchair users. Describing how workouts with others made him feel accountable to complete his own workout, P7 said, *"...for me, I know these women I've been doing rowing [with]- just having someone there with me, whether watching or just being with me holds me accountable and makes me want to do it, not for myself, but for the other person as well."*

Another participant, P5, felt motivated to exercise and stay fit so he could help uplift other people with similar injuries by **sharing lived experiences**. While talking about her father's determination to push himself through his injuries and be a source of informational support to others with SCI, F5 said:

> [...] you know, [P5] was [pause] [P5's] the person that was... you know, [P5's] going to push through, but [P5] does go around and speak to ...you know younger people who

> have... you know, spinal injuries, you know, and he tells a story, so you know, they don't like lose hope and they don't give up, you know. They keep pushing and keep growing, you know, so I would say that's something.

Being physically active made some of our participants feel a **sense of accomplishment**, whether it was through competing with others, reaching personal goals, or receiving social validation about their appearance. P8 was motivated by competing with others, saying: *"If you're in a… with a group of people, and everybody is competitive while you're there, you're competitive with each other at a point, that just keeps everybody motivated."* P1, P5 and P6 also enjoyed the feeling of competing with others in terms of PA, saying that it motivated them to perform better and reach their goals. P15 felt a sense of accomplishment from the social validation he received when people complimented his appearance when he regularly worked out: *"I think like the best motivation is somebody that tells you you're looking good […]."* P3 mentioned that she did not like the way her clothes fit on her when she was not physically active, which led her to want to work out regularly.

4.1.2 Fitness Tracking Tailored to Wheelchair-based Activities. Three participants reported using the Apple watch to track their PA, one reported using a Fitbit, and two participants mentioned that they had never used a fitness tracker because they tracked their activities based on distance and calorie readings from exercise equipment. Some participants mentioned that they were not satisfied with the current state of PA tracking software available commercially and that they felt this limited their ability to set goals and compete with others (Table 2).

P1 brought up the issue of how the Apple watch tracks wheelchair-based PA using a step count, saying *"[...] if this is going to be for the people using wheelchairs, or people with disability, it might be nice to be able to compete against someone who's in a similar situation versus like you know, I use [an] Apple Watch and if everyone is competing against how many steps and if you're not taking steps [because] you're in [a] wheelchair, then you know, you don't have that option to compete."* She strongly advocated for comparisons between similar people and a different approach to tracking PA than a step count. P16 highlighted an issue with how the Apple Watch converted wheelchair pushes to steps, saying *"[…] [the Apple Watch] says one of my pushes is three steps, that's not true if I'm going on a hill and I'm pushing a whole bunch more than people are picking up their feet to go up hills, so there's some things I would like [to see on the watch] […]."*

F9 is an individual with SCI who uses a power wheelchair and is a peer supporter to manual wheelchair users. She talked about wanting to **limit the app to wheelchair users only**, saying *"[...] someone who says I'm just going running is like, [sarcastically] well great, because I can't, and I know I see everyone else running outside, it's not really… they have other sports or things that they can do so, the whole idea of this app is for wheelchair users."* This came up in interviews with other participants who described how activities like running and walking were given priority in fitness applications while wheelchair-based activities were either not included or were present at the bottom of a long list of physical activities. P6 echoed this feeling of wheelchair users being included as an afterthought in many fitness tracking applications saying, *"Okay, so like with my [pause] with the other [fitness tracking applications] I've used, you have to scroll through all the other stuff to get to the wheelchair [activities]."* P15 wanted the app to be limited to wheelchair users because he found it hard to connect with other wheelchair users in his area: *"I really liked the idea of the entire app being people in wheelchairs, because it is really, really difficult to meet other people in wheelchairs and I think it'd be fun to commiserate with them."*

On the other hand, P10 usually exercised with individuals from the general population and expressed that limiting the app to just wheelchair users would be counterproductive. He said *"I see* *this app as being universal. I don't know that you necessarily should promote it just for people in wheelchairs [...]. The people that I know that do exercise are all able bodied, so I'd be more inclined to use this app with them."* P16 also felt similarly, saying *"I like including friends and family. Because people I compete with... I have regular riders to do workouts with, they ride along on their bicycles with me, so I kind of like that they can be included."*

4.1.3 Source of support impacts how the support is received. Source of support was an important factor in how messages were interpreted. Talking about how he regarded messages from his mother versus from his son, P2 said, *"[... the message] would just be more inspirational to motivate me, if it were [son's name], it would be a son that's telling me to go out and kick butt today versus my mother. So, I just [pause] you know [pause] both would be appreciated, but they would be interpreted differently, even if they meant the same thing."* We presented examples of motivational messages being sent both ways between the participant with SCI and their friend/family member to enable a reciprocal exchange of support. When asked how she would feel about receiving motivational messages to increase PA from her spouse P2, F2 answered:

> [...] because there's an element of me supporting him. I don't know if [him motivating me to exercise] would make me feel, 'Oh, he cares about me,' or if I would just be like, 'just get off my case,' you know. I don't know how I'd react to it. Because I know he cares about me and he wants me to be good to myself and do the things that I need to do, but I don't want to hear it from him, you know.

This perceived power differential came up multiple times in our interviews with P1, P2 and P3 all saying that they were usually the ones to initiate communication about their PA. Our initial assumption was that supporters would initiate PA-related communication, but the interviews pointed towards a general trend of persons with SCI being the ones to usually initiate such communication.

4.2 Phase 2: Storyboarding with low-fidelity app feature prototypes

Sessions 3 and 4 were mainly focused on communication between individuals with SCI and their friends and family to overcome barriers to PA identified in previous sessions and from prior literature (Table 2).

4.2.1 Communication to overcome barriers to PA. During the storyboarding sessions, we asked participants about how communication could help overcome barriers and what type of communication would be most encouraging. P3 mentioned using communication as a form of reassurance to navigate around pain:

> If you're having pain, maybe talking [about] it with somebody else, you know, could help you figure out a better plan to go with your exercise or activity. Especially if the other person has a bit more medical knowledge, you know, what else could you do that wouldn't use the part that's in pain, or like is it just really painful that maybe you should just rest. Communicating rather than trying to figure it out on your own might be nice.

P16 liked the idea of using a user forum to communicate regarding barriers to PA:

> If you have an open forum of somebody saying 'Hey I'm thinking about doing this, but I don't know how safe it is.' Other people probably give suggestions on how they could exercise safely, so that would be a good thing. Moods same way, somebody is feeling down, and I mean I don't know if you want to put like emojis on there so I log in and I got a smiley face or I got a frowny face or something so other people can see that and say

> [pause] and try to motivate that person 'hey I know you're feeling down today but I promise you, once we get through this exercise session together you'll be fine or you'll feel better,' so I don't know, that would help.

The message scheduling concept we demonstrated that allowed users to schedule messages to be sent in the future based on the occurrence of events like time of day, day of week, physical activity, and location received a mixed reception from our participants. P1 and P2 were worried about scheduled messages sounding automated and ingenuine, with P2 saying, "*[...] if it's preset it takes away the significance of it, it's less personal [...].*" On the other hand, three participants mentioned that the scheduling feature would be useful. F9 felt that the scheduling feature would save time, saying, "*if you've done it through the app, [it] allows you to track it and, you know, it's already written out, and it's what you're doing, you can then share it with friends. And I do find a lot of my friends always asking how I'm doing, and they want to know what's going on [in] your life, but sometimes you just don't have time to, you know, tell everyone.*"

Five of our participants reacted positively to our concept screens that could enable users to connect with each other to ask for, or to offer, help, and expressed a desire to connect with similar people digitally. P4 advocated for more ways to connect with others facing similar issues, saying, *"If there are forums out there, or some type of, you know, chat pages out there, or something where people that have similar physical disabilities can kind of talk amongst themselves and give each other ideas of what they've done."* We asked participants why they expressed an interest in this new communication forum versus using existing platforms such as Facebook that already allow formation of communities. Participants mentioned using technologies like Facebook, Reddit, Messenger, and WhatsApp to form groups where they could either message others or post on a public forum. Some participants indicated that they liked the idea of a forum specifically focused on exchanging help and advice to promote PA because on existing forum options it was sometimes hard to find information among the overwhelming amounts of information in crowded community forums such as on Reddit. Talking about this, P14 said:

> I do look at some Reddit groups mostly centered around spinal cord injuries, [to] see what people are up to. I'm also on web forums for spinal cord injuries to see what's new. I converse with other people who have similar ailments. But it's rare that physical activity is ever discussed. Other than how do I lose weight, or how do I get rid of a quad belly, or somebody selling the equipment.

4.2.2 Context and timing influence a message's impact. Some participants had preferences for the timing of incoming messages while engaging in PA, with many preferring not to be interrupted while exercising. Participants also expressed that their context when they received a message would affect their perception of the message and its contents. In the storyboarding sessions, we asked participants about the role context plays in the types of messages they send to friends and family members after showing them our prototype screens that enable message scheduling for a future time. All our participants agreed that the context of the recipient would influence the contents of the messages they sent. For instance, P1 and P2 were worried about scheduling congratulatory messages based on detected PA ahead of time because the sensors on the phone and watch might not be able to detect when someone fell and injured themselves during an activity. Talking about how he would rather wait to know the recipient's context before sending a message, P2 says:

> I'll still wait for whoever's doing that activity to message me because they might have had a really bad time... they could have finished [the] activity and the app senses it but

> they maybe had a really bad time and I wouldn't want to just send 'good job' automatically, without knowing how it went.

He also mentioned that he was usually the one who initiated communication about PA, something that was echoed by other participants with SCI, which led us to include an option in later sessions illustrating how messages could be scheduled based not only the recipient's activity, but also the message sender's activity.

In addition to context, timing of messages was another important aspect of how the recipients reacted to some possible messaging. Talking about his preferences for receiving notifications for incoming messages based on PA, P10 says: *"I would probably prefer it... not prefer it but... be more interested or more excited to get [messages based on PA] earlier."* P16 mentioned that he would prefer to receive encouraging messages related to his PA right after his workout: *"I would rather [receive the message] closer to the time that I finish [the PA]. I think it'll motivate me more to keep doing it, whereas if it's like hours later I'll probably go 'whatever'."* For many of our participants, receiving encouragement from others through a special notification tone on their phone in the middle of a workout was more likely to motivate them to reach their PA goals.

When we initially talked to participants about the message scheduling capabilities of our proposed application, they found it hard to create content for scheduled messages ahead of time. To help users learn how to use context triggers (location, PA, and time) with their messages, we showed them concept screens for fill-in-the-blank-style message templates that would show them how they could schedule messages based on different events (Fig. 6b). We received mixed reactions to these templates, with three participants feeling that the templates would make communication seem less personal and two participants saying that the templates would make creating messages easier. The rest of our participants did not express any opinion about the templates. On asking participants about why the templates seemed less personal, they explained that they would not use the language in the templates with their friend or family member, making the message seem inauthentic. To allow users to add personal touches to messages they sent based on the template, we added an option to edit the contents of the message. We also added in question style templates that can initiate a conversation without making assumptions about the recipient's context. The question style templates were preferred over the fill in the blank style templates by at least six of our participants because the question-style templates did not make assumptions that the experience of engaging in a physical activity was necessarily positive. Talking about how he was uncomfortable scheduling a congratulatory message without knowing the receiver's context, P2 says:

> [...] maybe like "how's the view" or "how's it going for you", something that would be more of a question, I guess, because you just don't know... did they pop a tire, did they fall off, did they get stung by a bee, you don't know what the circumstances are to say you're doing great, because it's presumed that that's what it is, and you don't really know.

5 DISCUSSION

Participants collectively expressed a desire for a targeted app that might enable them to connect with similar people or a group of people. They further identified situations where they might find a context-aware messaging application useful in communicating about PA, and they provided insight into how an mHealth application might assist with behavioral change aimed at improving PA levels for individuals with SCI. In this section, we discuss opportunities and challenges for interventions to motivate PA in individuals with SCI facilitated by context-aware messaging applications.

5.1 Real-time Social Support and Encouragement to Increase PA Levels

One of the reasons mentioned by participants to engage in PA was to socialize with others and achieve goals together. Workout buddies and similar forms of accountability are known to increase adherence to PA goals and PA levels [16, 54]. Context-aware content delivery [31, 42, 84], and text messaging [53, 58] have also been used in interventions in the past to create a feeling of accountability and increase user motivation to complete PA goals with varying degrees of success. An application that combines these three components together could potentially improve PA levels.

Manual wheelchair users may have to exercise on their own sometimes, and often use both of their arms to propel their wheelchair, making it difficult to text back and forth via typing while moving [25]. Having the option to schedule messages for delivery based on the detection of the recipient's context might allow them to provide or receive in-the-moment support, without interrupting their own activity. Such a feature might make the recipients of these messages feel connected while also providing timely motivation to exercise, addressing **RQ2**.

Participants had mixed reactions towards the message scheduling features presented in our concept screens. Some participants felt that scheduling based on future context of a recipient without knowing what it might be would make their messages sound ingenuine, while others felt that the message scheduling features would help them initiate timely conversations. To alleviate this worry about messages sounding ingenuine, we presented participants with options of (1) question templates that asked about the details of a particular activity that was detected by the phone and (2) messages triggered by a user's own activity. Both options were received positively by participants to gauge the context of a friend, and participants indicated that it could help them receive timely social support to overcome one of the barriers to PA: social support, addressing **RQ1**.

Participants considered goal-tracking to be a useful event to schedule messages based on. Being notified when one is close to achieving a PA goal has been known to motivate users to follow through and attain their goal [44, 61]. We recommend quantifying and tracking the percentage of an activity goal that has been completed to enable message delivery based on goal completion rates. For instance, scheduling a message to be sent when a recipient is half-way through an activity goal might result in the recipient feeling that someone else is invested in the recipient's progress. If that message is well-crafted, it might motivate the person exercising to keep going or increase the intensity of the activity. To support general quantifiable PA goal progress tracking in individuals with SCI, goals could be set either in terms of overall arm movement [64], duration of activity (minutes), or distance covered (miles), addressing **RQ2**.

Additionally, participants also mentioned that commercially available smartwatches which participants use to track their PA often tracks their wheelchair-based activity inaccurately, even though Apple smartwatches now track wheelchair-based activities separately from steps [10]. PHIRE [31] uses custom software to classify and track wheelchair-based PA using accelerometer data from a wrist-worn smartwatch with high accuracy. Extending the tracking methodology used in applications such as PHIRE could make PA tracking a more pleasant experience for wheelchair users.

5.2 Facilitating Meaningful Conversations Using Templates and Open-ended Conversations

Our interviews helped us understand some of the barriers individuals with SCI face in performing PA (Table 2). Consistent with barriers identified in prior literature, participants reported weather, accessibility [69-71], cost of equipment [69, 70], lack of help [69], lack of information [68], and limited availability of resources – both personal and shared [69, 71]– as barriers. In addition, pain, mood, and depression were also mentioned as barriers to PA in our interviews, which is again consistent with findings from prior literature [35, 47, 71, 81]. Participants explained that timely communication could help overcome some of the barriers to PA, but we found that participants struggled to think about conversation starters in the activities that required them to create content to encourage PA. Having the app assist them in composing a message might help start and continue conversations; this assistance might be achieved using carefully curated message templates. Mad Libs [2] - a game where you fill in the blanks with words of your choice - has been used in the past to enable generation of humorous content while reducing the cognitive burden of having to come up with the entire content [32]. We took inspiration from Mad Libs to create some message templates that could aid content creation. Of the two types of templates that we showed participants to assist them in sending real-time messages, open-ended questions provoking self-reflection were preferred over fill-in-the-blank style templates that had a few empty spaces users were supposed to fill with a word/phrase (Fig. 6b). For messages that participants were asked to schedule based on the occurrence of an event or set of events in the future, they indicated that they would prefer knowing about the recipient's context rather than making an assumption about it. This sentiment was expressed multiple times in Session 3, with participants saying that they would be hesitant to schedule a congratulatory message to be delivered in the future based on events detected by the smartwatch and/or phone; they expressed concern that the activity may have falsely detected when there was none, or that the recipient may have completed the PA while being in pain or injured.

To mitigate this problem, we suggest the use of 'inquisitory' question templates; rather than only focusing on congratulatory messages, the system would encourage senders to create clever messages of inquiry about how a detected activity went. By encouraging communication that is asking questions, the sender can avoid assuming that the recipient's activity went well. Sending a well-worded question as a message also has the added benefit of *starting* a conversation (versus being a more declarative, and perhaps finalizing congratulatory remark) and opening the door of the conversation for both the recipient *and* sender to talk about their activities, addressing **RQ1**. For example, one of the question templates that was received positively by six participants was 'Did you go for a roll today? How did you feel after returning?' We know that framing of messaging affects its persuasive impact [87]; our work suggests intervention developers should invest effort framing messages in open-ended, inquisitory ways that will simultaneously stimulate engagement and acknowledge activity, but while avoiding some potential user concerns about messages being taken out of context.

5.3 Providing Opportunities to Start Conversations

Initially, we had only included the option in the application concept materials to schedule messages to be delivered based on the *recipient's* PA. We assumed that messages of encouragement would typically be initiated by the supporters of those with SCI. However, in our interviews, participants with SCI mentioned that they usually initiated the conversation about PA. And, more significantly, many participants felt uncomfortable sending encouraging or congratulatory messages without knowing the recipient's context. We thus recommend that an app include the option of scheduling messages based on one's *own* self-detected activity. This way, the person who wishes to obtain additional support for PA can safely initiate context-sensitive messaging about the PA – and in a way that will put friends and family at ease.

Some of our participants expressed frustration at the lack of a targeted means to digitally connect with others with similar disabilities in our interview sessions. They indicated that Facebook groups included too much information not directly relevant to them, thus diminishing utility. A platform for wheelchair users to connect with similar people was positively regarded by many of our participants, with many saying that they would prefer it over other existing platforms that cater to everyone. However, they were also some participants who mentioned that they would prefer if the app were open to everyone, as they usually exercised with friends from the non-SCI population. To cater to all participants' needs, we recommend designing the app with the central function of allowing users with SCI to connect to each other, but also allowing the option to connect to other friends and family if one wishes to do so.

The need for a tailored platform to connect with others when participants needed physical assistance was also mentioned. Physical assistance is one of the forms of social support that affects PA levels in individuals with SCI [35, 81]. This is a much more difficult problem to solve because it needs scheduling and coordination between multiple people and resources such as safe and accessible transportation. We will explore this in our future work.

5.4 Opportunities to Improve PA in Other Populations Using Context-Aware Messaging

Lack of information about safe PA guidelines, and PA information not being tailored to disabilities are commonly reported barriers to being physically active among populations with physical disabilities [51, 63]. A qualitative study exploring using communication technologies to facilitate easier access to information found that finding the right audience and targeting information to them through social media (similar to targeted advertising) could improve access to information [34]. Participants also reported that having information from multiple sources would increase the access to information. The messaging framework that we explored also included a forum where users could connect with a community of similar people and have targeted discussions about PA. This feature, in addition to peer-to-peer messaging can be extended to people with disabilities to facilitate tailored and informative PA content.

In the general population, mobile health applications have used strategies such as text messaging [8, 75, 80], improving accuracy of reported PA to increase user trust in these systems [11, 19, 85], and just-in-time feedback [42, 84], to improve PA levels. Many of these applications suffered from dropping engagement levels and high user attrition rates as time progressed [8, 22, 26]. mHealth applications that incorporated peer-to-peer communication in some form (text messaging, in-app messaging, forums, other existing social media platforms) saw higher levels of user engagement and better health outcomes [13, 37, 39]. Several qualitative studies also found that supporting peer-to-peer communication within mHealth applications can improve user engagement levels, which in turn can improve the efficacy of PA interventions [64, 78].

Based on prior research about communication improving engagement in mHealth applications, we explored a context-aware messaging framework that retains the elements of text messaging that mobile phone users are familiar with while also providing additional scheduling capabilities not found in regular text messaging applications. Many of the themes we found while interviewing our participants with SCI can be extended to other populations. For instance, context-aware messaging in other populations can also provide users with a platform to exchange just-in-time tailored messages to overcome barriers to PA. In the general population, these barriers include lack of time, mood, lack of social support, or lack of energy [6, 7]. Many of these barriers were also reported by our participants with SCI. In our storyboarding and interview sessions, participants with SCI reported that receiving context-aware messages in a timely manner could help them overcome some barriers to PA. Another theme that can be extended to other populations is the influence of timing and context on the impact of a message in addition to the message's contents. Allowing message senders to schedule messages based on events that occur at the recipient's end can increase the impact of the delivered message. Being able to generalize these themes for others suggests that context-aware messaging can be easily extended to other populations to provide real-time social support and encouragement to improve PA levels.

6 LIMITATIONS

Persons with SCI deal with many challenges in their lives related to time, mobility, and physical health; participating in research projects is thus a substantial commitment. As a result, studies with this population – especially those using participatory design – are often small, and this study, with 15 participants with SCI, is no exception. We were limited to four sessions for each dyad. Due to the COVID-19 pandemic, some of the individuals did not have the ability to visit accessible outpatient wellness clinics. This limited our ability to meet individuals with SCI and recruit them into the study. Moreover, in this community, social isolation and feelings of not wanting to be a burden to others are not uncommon [57], and nine participants were unable to help us identify a friend or family member. After attempting to recruit 40 people who could not name friends or family members who they would ask to participate, we changed procedures to allow some individuals to participate alone. The difficulty some participants have in identifying social support is an area we have left for future work – here we explicitly explored the potential of dyad communication – and yet not all persons with SCI may even feel comfortable engaging a friend or family member for support. Additionally, four participants were unable to complete later sessions due to re-hospitalization or other health reasons. In general, about 30% of persons with SCI are re-hospitalized one or more times during any given year following injury [1], which may be why they are under-served by the research community.

A frequent theme brought up during the interviews relates to the physical assistance needed to perform certain activities. There is a limit to what *any* potential mobile application might be able to do to assist with this problem.

In this work, we assume, based on promising prior work (e.g. [31]), that activities and contexts of interest can be detected using devices such as smartwatches, and that people with SCI would be willing to wear them. The detection systems will make mistakes; however, an activity will not be detected if the smartwatch is not worn, or the smartphone is not present with the person. Applications that use interactive sensing will need to accommodate such challenges with graceful degradation of performance that does not confuse the people communicating with each other, but these challenges are best explored with real-time implementations of the full system.

7 CONCLUSION

Through our participatory design study, we identified barriers and motivators to PA among individuals with SCI and how communication might help overcome some of these barriers. Our findings characterize the role social interactions play in PA levels in this population, the influence of context on timing on message reception, how communication can help overcome barriers to PA, and how context-aware messages can create a feeling of social support being available when such support is needed in a timely and tailored manner. We further investigated participant reception to a context-aware messaging application to provide timely social support and identified the benefits of such an application to individuals with limited mobility. We propose approaches to identify significant events to facilitate conversations about PA and offer just-in-time support using context-aware messaging on mobile devices.

ACKNOWLEDGMENTS

This research is funded by a research grant (90IFDV0018) from the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR), Administration of Community Living (ACL), US Department of Health and Human Services.

REFERENCES

[1] National Spinal Cord Injury Statistical Center. 2020. *The 2020 Annual Statistical Report Complete Public Version for the Spinal Cord Injury Model Systems.* (Accessed January 4th, 2022); Available from: https://www.nscisc.uab.edu/public/2020%20Annual%20Report%20-%20Complete%20Public%20Version.pdf.

[2] *Mad Libs- The World's Greatest Word Game.* (Accessed January 4th, 2022); Available from: https://www.madlibs.com/.

[3] World Health Organization. 2013. *Spinal Cord Injury* (Accessed January 4th, 2022); Available from: https://www.who.int/news-room/fact-sheets/detail/spinal-cord-injury.

[4] National Spinal Cord Injury Statistical Center. 2021. *Spinal Cord Injury Facts and Figures at a Glance.* (Accessed 4th January, 2022); Available from: https://www.nscisc.uab.edu/Public/Facts%20and%20Figures%20-%202021.pdf.

[5] Gregory D Abowd, Gillian R Hayes, Giovanni Iachello, Julie A Kientz, Shwetak N Patel, Molly M Stevens, and Khai N Truong. 2005. Prototypes and paratypes: Designing mobile and ubiquitous computing applications. *IEEE Pervasive Computing*, **4**(4): p. 67-73.

[6] Kenneth R Allison, John JM Dwyer, and Susan Makin. 1999. Perceived barriers to physical activity among high school students. *Preventive Medicine*, **28**(6): p. 608-615.

[7] Daskapan Arzu, Emine Handan Tuzun, and Levent Eker. 2006. Perceived barriers to physical activity in university students. *Journal of Sports Science & Medicine*, **5**(4): p. 615.

[8] Patricia Avila-Garcia, Rosa Hernandez-Ramos, Sarah S Nouri, Anupama Cemballi, Urmimala Sarkar, Courtney R Lyles, and Adrian Aguilera. 2019. Engaging users in the design of an mHealth, text message-based intervention to increase physical activity at a safety-net health care system. *JAMIA open*, **2**(4): p. 489-497.

[9] AJT Bakkum, S De Groot, JM Stolwijk-Swüste, DJ Van Kuppevelt, LHV Van Der Woude, and TWJ Janssen. 2015. Effects of hybrid cycling versus handcycling on wheelchair-specific fitness and physical activity in people with long-term spinal cord injury: A 16-week randomized controlled trial. *Spinal Cord*, **53**(5): p. 395-401.

[10] Nils-Hendrik Benning, Petra Knaup, and Rüdiger Rupp. 2020. Comparison of accuracy of activity measurements with wearable activity trackers in wheelchair users: A preliminary evaluation. *GMS Med Inform Biom Epidemiol*, **16**(2).

[11] Judit Bort-Roig, Nicholas D Gilson, Anna Puig-Ribera, Ruth S Contreras, and Stewart G Trost. 2014. Measuring and influencing physical activity with smartphone technology: A systematic review. *Sports Medicine*, **44**(5): p. 671-686.

[12] Virginia Braun and Victoria Clarke, Thematic analysis. 2012.

[13] Elizabeth Burner, Chun Nok Lam, Rebecca DeRoss, Marjorie Kagawa-Singer, Michael Menchine, and Sanjay Arora. 2018. Using mobile health to improve social support for low-income Latino patients with diabetes: A mixed-methods analysis of the feasibility trial of TExT-MED+ FANS. *Diabetes Technology & Therapeutics*, **20**(1): p. 39-48.

[14] Patrick Carrington, Kevin Chang, Helena Mentis, and Amy Hurst. 2015. "But, I don't take steps" Examining the inaccessibility of fitness trackers for wheelchair athletes. in *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility.* p. 193-201.

[15] Patrick Carrington, Amy Hurst, and Shaun K Kane. 2014. Wearables and chairables: Inclusive design of mobile input and output techniques for power wheelchair users. in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* p. 3103-3112.

[16] Yu Chen, Jiyong Zhang, and Pearl Pu. 2014. Exploring social accountability for pervasive fitness apps. in *Proceedings of the Eighth International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies.* p. 221-226.

[17] Sanghee Chun and Youngkhill Lee. 2010. The role of leisure in the experience of posttraumatic growth for people with spinal cord injury. *Journal of Leisure Research*, **42**(3): p. 393-415.

[18] Elaine H Coulter, Philippa M Dall, Lynn Rochester, Jon P Hasler, and Malcolm H Granat. 2011. Development and validation of a physical activity monitor for use on a wheelchair. *Spinal Cord*, **49**(3): p. 445-450.

[19] Herman J de Vries, Thea JM Kooiman, Miriam W van Ittersum, Marco van Brussel, and Martijn de Groot. 2016. Do activity monitors increase physical activity in adults with overweight or obesity? A systematic review and meta-analysis. *Obesity*, **24**(10): p. 2078-2091.

[20] Carlo C DiClemente and James O Prochaska. 1998. Toward a comprehensive, transtheoretical model of change: Stages of change and addictive behaviors. *Treating Addictive Behaviors*: p. 3–24.

[21] Anestis Divanoglou and M Georgiou. 2017. Perceived effectiveness and mechanisms of community peer-based programmes for spinal cord injuries—a systematic review of qualitative findings. *Spinal Cord*, **55**(3): p. 225-234.

[22] Katie L Druce, William G Dixon, and John McBeth. 2019. Maximizing engagement in mobile health studies: Lessons learned and future directions. *Rheumatic Disease Clinics*, **45**(2): p. 159-172.

[23] Julie Gassaway, Michael L Jones, W Mark Sweatman, Minna Hong, Peter Anziano, and Karen DeVault. 2017. Effects of peer mentoring on self-efficacy and hospital readmission after inpatient rehabilitation of individuals with spinal cord injury: a randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, **98**(8): p. 1526-1534. e2.

[24] KA Martin Ginis, AL Hicks, AE Latimer, DER Warburton, C Bourne, DS Ditor, DL Goodwin, KC Hayes, N McCartney, and A McIlraith. 2011. The development of evidence-informed physical activity guidelines for adults with spinal cord injury. *Spinal Cord*, **49**(11): p. 1088-1096.

[25] Victoria Louise Goosey-Tolfrey and Jennifer Helen Kirk. 2003. Effect of push frequency and strategy variations on economy and perceived exertion during wheelchair propulsion. *European Journal of Applied Physiology*, **90**(1): p. 154-158.

[26] Diana Guertler, Corneel Vandelanotte, Morwenna Kirwan, and Mitch J Duncan. 2015. Engagement and nonusage attrition with a free physical activity promotion program: The case of 10,000 steps Australia. *Journal of Medical Internet Research*, **17**(7): p. e4339.

[27] David H Gustafson, Fiona M McTavish, Ming-Yuan Chih, Amy K Atwood, Roberta A Johnson, Michael G Boyle, Michael S Levy, Hilary Driscoll, Steven M Chisholm, and Lisa Dillenburg. 2014. A smartphone application to support recovery from alcoholism: A randomized clinical trial. *JAMA Psychiatry*, **71**(5): p. 566-572.

[28] Elizabeth M Hannold, Mary Ellen Young, Maude R Rittman, Mark G Bowden, and Andrea L Behrman. 2006. Locomotor training: Experiencing the changing body. *Journal of Rehabilitation Research and Development*, **43**(7): p. 905-916.

[29] Severin Haug, Raquel Paz Castro, Andreas Filler, Tobias Kowatsch, Elgar Fleisch, and Michael P Schaub. 2014. Efficacy of an Internet and SMS-based integrated smoking cessation and alcohol intervention for smoking cessation in young people: study protocol of a two-arm cluster randomised controlled trial. *BMC public health*, **14**(1): p. 1-8.

[30] Robert P Hawkins, Matthew Kreuter, Kenneth Resnicow, Martin Fishbein, and Arie Dijkstra. 2008. Understanding tailoring in communicating about health. *Health education research*, **23**(3): p. 454-466.

[31] Shivayogi V Hiremath, Amir Mohammad Amiri, Binod Thapa-Chhetry, Gretchen Snethen, Mary Schmidt-Read, Marlyn Ramos-Lamboy, Donna L Coffman, and Stephen S Intille. 2019. Mobile health-based physical activity intervention for individuals with spinal cord injury in the community: A pilot study. *PloS One*, **14**(10): p. e0223762.

[32] Nabil Hossain, John Krumm, Lucy Vanderwende, Eric Horvitz, and Henry Kautz. 2017. Filling the blanks (hint: plural noun) for mad libs humor. in *Proceedings of the 2017 Conference on Empirical Methods in Natural Language Processing*. p. 638-647.

[33] Bethlyn Vergo Houlihan, Sarah Everhart-Skeels, Damara Gutnick, Diana Pernigotti, Judi Zazula, Miriam Brody, Sam Burnett, Hannah Mercier, Stathis Hasiotis, and Christa Green. 2016. Empowering adults with chronic spinal cord injury to prevent secondary conditions. *Archives of Physical Medicine and Rehabilitation*, **97**(10): p. 1687-1695. e5.

[34] Eva A Jaarsma, Damian Haslett, and Brett Smith. 2019. Improving communication of information about physical activity opportunities for people with disabilities. *Adapted Physical Activity Quarterly*, **36**(2): p. 185-201.

[35] Matthew Kehn and Thilo Kroll. 2009. Staying physically active after spinal cord injury: A qualitative exploration of barriers and facilitators to exercise participation. *BMC Public Health*, **9**(1): p. 1-11.

[36] Corey LM Keyes, Dov Shmotkin, and Carol D Ryff. 2002. Optimizing well-being: The empirical encounter of two traditions. *Journal of Personality and Social Psychology*, **82**(6): p. 1007.

[37] Ashraf Khalil and Salam Abdallah. 2013. Harnessing social dynamics through persuasive technology to promote healthier lifestyle. *Computers in Human Behavior*, **29**(6): p. 2674-2681.

[38] Dong-il Kim, Jeongmin Lee, Hyuna Park, and Justin Y Jeon. 2020. The relationship between physical activity levels and mental health in individuals with spinal cord injury in South Korea. *International journal of environmental research and public health*, **17**(12): p. 4423.

[39] Abby C King, Eric B Hekler, Lauren A Grieco, Sandra J Winter, Jylana L Sheats, Matthew P Buman, Banny Banerjee, Thomas N Robinson, and Jesse Cirimele. 2016. Effects of three motivationally targeted mobile device applications on

initial physical activity and sedentary behavior change in midlife and older adults: A randomized trial. *PloS One*, **11**(6): p. e0156370.

[40] S Kiran, J Sanjana, and NJ Reddy. 2019. Mobile phone addiction: symptoms, impacts and causes-a review. in *Int Conf Trends Ind Value Eng Bus Soc Innov.*

[41] Paul N Kizakevich, Randall Eckhoff, Janice Brown, Stephen J Tueller, Belinda Weimer, Stacey Bell, Adam Weeks, Laurel L Hourani, James L Spira, and Laurel A King. 2018. PHIT for duty, a mobile application for stress reduction, sleep improvement, and alcohol moderation. *Military Medicine*, **183**(suppl_1): p. 353-363.

[42] Predrag Klasnja, Shawna Smith, Nicholas J Seewald, Andy Lee, Kelly Hall, Brook Luers, Eric B Hekler, and Susan A Murphy. 2019. Efficacy of contextually tailored suggestions for physical activity: A micro-randomized optimization trial of HeartSteps. *Annals of Behavioral Medicine*, **53**(6): p. 573-582.

[43] Hedwig Kooijmans, Marcel WM Post, Henk J Stam, Lucas HV Van der Woude, Dorien CM Spijkerman, Govert J Snoek, Helma MH Bongers-Janssen, CF Van Koppenhagen, Jos W Twisk, and ALLRISC Group. 2017. Effectiveness of a self-management intervention to promote an active lifestyle in persons with long-term spinal cord injury: The HABITS randomized clinical trial. *Neurorehabilitation and Neural Repair*, **31**(12): p. 991-1004.

[44] Daniel St Clair Kreitzberg, Stephanie L Dailey, Teresa M Vogt, Donald Robinson, and Yaguang Zhu. 2016. What is your fitness tracker communicating?: Exploring messages and effects of wearable fitness devices. *Qualitative Research Reports in Communication*, **17**(1): p. 93-101.

[45] Stephen M Levins, Darlene M Redenbach, and Isabel Dyck. 2004. Individual and societal influences on participation in physical activity following spinal cord injury: A qualitative study. *Physical Therapy*, **84**(6): p. 496-509.

[46] Ellie Lisitsa, Katherine S Benjamin, Sarah K Chun, Jordan Skalisky, Lauren E Hammond, and Amy H Mezulis. 2020. Loneliness among young adults during COVID-19 pandemic: The mediational roles of social media use and social support seeking. *Journal of Social and Clinical Psychology*, **39**(8): p. 708-726.

[47] Monika Löfgren and Cecilia Norrbrink. 2012. "But I know what works"–patients' experience of spinal cord injury neuropathic pain management. *Disability and Rehabilitation*, **34**(25): p. 2139-2147.

[48] Luca Lonini, Timothy Reissman, Jose M Ochoa, Chaithanya K Mummidisetty, Konrad Kording, and Arun Jayaraman. 2017. Sensor fusion to infer locations of standing and reaching within the home in incomplete spinal cord injury. *American Journal of Physical Medicine & Rehabilitation*, **96**(10 Suppl 1): p. S128.

[49] Kim Ludwig, Rosie Arthur, Nicholas Sculthorpe, Hollie Fountain, and Duncan S Buchan. 2018. Text messaging interventions for improvement in physical activity and sedentary behavior in youth: systematic review. *JMIR mHealth and uHealth*, **6**(9): p. e10799.

[50] Patricia J Manns and Karen E Chad. 2001. Components of quality of life for persons with a quadriplegic and paraplegic spinal cord injury. *Qualitative Health Research*, **11**(6): p. 795-811.

[51] Jeffrey J Martin. 2013. Benefits and barriers to physical activity for individuals with disabilities: a social-relational model of disability perspective. *Disability and rehabilitation*, **35**(24): p. 2030-2037.

[52] KA Martin, AE Latimer, C Francoeur, Heather Hanley, K Watson, AL Hicks, and N McCartney. 2002. Sustaining exercise motivation and participation among people with spinal cord injuries-Lessons learned from a 9-month intervention. *Palaestra-Macomb Illinois*, **18**(1): p. 38-40.

[53] Pamela McCoy, Sophia Leggett, Azad Bhuiyan, David Brown, Patricia Frye, and Bryman Williams. 2017. Text messaging: An intervention to increase physical activity among African American participants in a faith-based, competitive weight loss program. *International Journal of Environmental Research and Public Health*, **14**(4): p. 326.

[54] Sean A Munson, Erin Krupka, Caroline Richardson, and Paul Resnick. 2015. Effects of public commitments and accountability in a technology-supported physical activity intervention. in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems.* p. 1135-1144.

[55] Inbal Nahum-Shani, Eric B Hekler, and Donna Spruijt-Metz. 2015. Building health behavior models to guide the development of just-in-time adaptive interventions: A pragmatic framework. *Health Psychology*, **34**(S): p. 1209-1219.

[56] Felix Naughton, Sarah Hopewell, Neal Lathia, Rik Schalbroeck, Chloë Brown, Cecilia Mascolo, Andy McEwen, and Stephen Sutton. 2016. A context-sensing mobile phone app (Q sense) for smoking cessation: a mixed-methods study. *JMIR mHealth and uHealth*, **4**(3): p. e5787.

[57] Susan D Newman, Chao Li, and James S Krause. 2016. Social isolation after spinal cord injury: Indicators from the longitudinal aging study. *Rehabilitation Psychology*, **61**(4): p. 408-416.

[58] Kirsty H Newton, Esko J Wiltshire, and C Raina Elley. 2009. Pedometers and text messaging to increase physical activity: Randomized controlled trial of adolescents with type 1 diabetes. *Diabetes Care*, **32**(5): p. 813-815.

[59] Tom E Nightingale, Peter C Rouse, Jean-Philippe Walhin, Dylan Thompson, and James LJ Bilzon. 2018. Home-based exercise enhances health-related quality of life in persons with spinal cord injury: A randomized controlled trial. *Archives of Physical Medicine and Rehabilitation*, **99**(10): p. 1998-2006. e1.

[60] Carla FJ Nooijen, Henk J Stam, Michael P Bergen, Helma MH Bongers-Janssen, Linda Valent, Sacha van Langeveld, Jos Twisk, Rita JG van den Berg-Emons, and Act-Active Research Group. 2016. A behavioural intervention increases

physical activity in people with subacute spinal cord injury: A randomised trial. *Journal of Physiotherapy*, **62**(1): p. 35-41.

[61] Kayla Nuss and Kaigang Li. 2021. Motivation for physical activity and physcial activity engagement in current and former wearable fitness tracker users: A mixed-methods examination. *Computers in Human Behavior*, **121**: p. 106798.

[62] Aron O'Brien, Rebecca Renwick, and Karen Yoshida. 2008. Leisure participation for individuals living with acquired spinal cord injury. *International Journal of Rehabilitation Research*, **31**(3): p. 225-230.

[63] Marie-Josée Perrier and Kathleen A Martin Ginis.2017. Communicating physical activity information to people with physical disabilities, in *Persuasion and communication in sport, exercise, and physical activity.* Routledge. p. 233-249.

[64] Karin Postma, JBJ Bussmann, TAR Sluis, MP Bergen, and HJ Stam. 2005. Validity of the detection of wheelchair propulsion as measured with an activity monitor in patients with spinal cord injury. *Spinal Cord*, **43**(9): p. 550-557.

[65] Pollie Price, Stephanie Stephenson, Lesha Krantz, and Kristine Ward. 2011. Beyond my front door: The occupational and social participation of adults with spinal cord injury. *OTJR: Occupation, Participation and Health*, **31**(2): p. 81-88.

[66] Mashfiqui Rabbi, Meredith Philyaw-Kotov, Jinseok Lee, Anthony Mansour, Laura Dent, Xiaolei Wang, Rebecca Cunningham, Erin Bonar, Inbal Nahum-Shani, and Predrag Klasnja. 2017. SARA: A mobile app to engage users in health data collection. in *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers.* p. 781-789.

[67] Ian M Rice, Laura A Rice, and Robert W Motl. 2015. Promoting physical activity through a manual wheelchair propulsion intervention in persons with multiple sclerosis. *Archives of Physical Medicine and Rehabilitation*, **96**(10): p. 1850-1858.

[68] James A Rimmer and Jennifer L Rowland. 2008. Physical activity for youth with disabilities: A critical need in an underserved population. *Developmental Neurorehabilitation*, **11**(2): p. 141-148.

[69] James H Rimmer. 2005. The conspicuous absence of people with disabilities in public fitness and recreation facilities: Lack of interest or lack of access? *American Journal of Health Promotion*, **19**(5): p. 327-329.

[70] James H Rimmer, Sangeetha Padalabalanarayanan, Laurie A Malone, and Tapan Mehta. 2017. Fitness facilities still lack accessibility for people with disabilities. *Disability and Health Journal*, **10**(2): p. 214-221.

[71] James H Rimmer, Barth Riley, Edward Wang, Amy Rauworth, and Janine Jurkowski. 2004. Physical activity participation among persons with disabilities: Barriers and facilitators. *American Journal of Preventive Medicine*, **26**(5): p. 419-425.

[72] James H Rimmer and Jennifer L Rowland. 2008. Health promotion for people with disabilities: Implications for empowering the person and promoting disability-friendly environments. *American Journal of Lifestyle Medicine*, **2**(5): p. 409-420.

[73] James H Rimmer, William Schiller, and Ming-De Chen. 2012. Effects of disability-associated low energy expenditure deconditioning syndrome. *Exercise and Sport Sciences Reviews*, **40**(1): p. 22-29.

[74] Muhammad Saud, Musta'in Mashud, and Rachmah Ida. 2020. Usage of social media during the pandemic: Seeking support and awareness about COVID-19 through social media platforms. *Journal of Public Affairs*, **20**(4): p. e2417.

[75] Andreas R Schwerdtfeger, Catalina Schmitz, and Matthias Warken. 2012. Using text messages to bridge the intention-behavior gap? A pilot study on the use of text message reminders to increase objectively assessed physical activity in daily life. *Frontiers in Psychology*, **3**: p. 270.

[76] Reinhard Sefelin, Manfred Tscheligi, and Verena Giller. 2003. Paper prototyping-what is it good for? A comparison of paper-and computer-based low-fidelity prototyping. in *CHI'03 Extended Abstracts on Human Factors in Computing Systems.* p. 778-779.

[77] Tamar Semerjian, Suzanne Montague, Jesus Dominguez, Artin Davidian, and Ray de Leon. 2005. Enhancement of quality of life and body satisfaction through the use of adapted exercise devices for individuals with spinal cord injuries. *Topics in Spinal Cord Injury Rehabilitation*, **11**(2): p. 95-108.

[78] Ryan Shaw and Hayden Bosworth. 2012. Short message service (SMS) text messaging as an intervention medium for weight loss: a literature review. *Health informatics journal*, **18**(4): p. 235-250.

[79] Sally A Shumaker and Arlene Brownell. 1984. Toward a theory of social support: Closing conceptual gaps. *Journal of social issues*, **40**(4): p. 11-36.

[80] Lauren C Spark, Brianna S Fjeldsoe, Elizabeth G Eakin, and Marina M Reeves. 2015. Efficacy of a text message-delivered extended contact intervention on maintenance of weight loss, physical activity, and dietary behavior change. *JMIR mHealth and uHealth*, **3**(3): p. e4114.

[81] Catherine Stephens, Rich Neil, and Paul Smith. 2012. The perceived benefits and barriers of sport in spinal cord injured individuals: A qualitative study. *Disability and Rehabilitation*, **34**(24): p. 2061-2070.

[82] Anselm Strauss and Juliet Corbin, Basics of qualitative research. 1990: Sage publications.

[83] AE Tawashy, JJ Eng, KH Lin, PF Tang, and C Hung. 2009. Physical activity is related to lower levels of pain, fatigue and depression in individuals with spinal-cord injury: A correlational study. *Spinal Cord*, **47**(4): p. 301-306.

[84] J Graham Thomas and Dale S Bond. 2015. Behavioral response to a just-in-time adaptive intervention (JITAI) to reduce sedentary behavior in obese adults: Implications for JITAI optimization. *Health Psychology*, **34**(Suppl): p. 1261-1267.

[85] Daniel Trommler, Christiane Attig, and Thomas Franke. 2018. Trust in activity tracker measurement and its link to user acceptance. in *Mensch und Computer 2018-Tagungsband*.

[86] Khai N Truong, Gillian R Hayes, and Gregory D Abowd. 2006. Storyboarding: An empirical determination of best practices and effective guidelines. in *Proceedings of the 6th Conference on Designing Interactive Systems*. p. 12-21.

[87] Amos Tversky and Daniel Kahneman. 1991. Loss aversion in riskless choice: A reference-dependent model. *The Quarterly Journal of Economics*, **106**(4): p. 1039-1061.

[88] Leontine Van De Ven, Marcel Post, Luc De Witte, and Wim Van Den Heuvel. 2008. Strategies for autonomy used by people with cervical spinal cord injury: A qualitative study. *Disability and Rehabilitation*, **30**(4): p. 249-260.

[89] Lizanne E van den Akker, Jasmijn FM Holla, Tessa Dadema, Bart Visser, Linda J Valent, Sonja de Groot, Joan M Dallinga, Marije Deutekom, and WHEELS-Study Group. 2020. Determinants of physical activity in wheelchair users with spinal cord injury or lower limb amputation: perspectives of rehabilitation professionals and wheelchair users. *Disability and Rehabilitation*, **42**(14): p. 1934-1941.

[90] Catherine Warms. 2006. Physical activity measurement in persons with chronic and disabling conditions: Methods, strategies, and issues. *Family & Community Health*, **29**(1): p. 78S-88S.

[91] Catherine A Warms and Basia L Belza. 2004. Actigraphy as a measure of physical activity for wheelchair users with spinal cord injury. *Nursing research*, **53**(2): p. 136-143.

[92] Richard A Washburn, Weimo Zhu, Edward McAuley, Michael Frogley, and Stephen F Figoni. 2002. The physical activity scale for individuals with physical disabilities: Development and evaluation. *Archives of Physical Medicine and Rehabilitation*, **83**(2): p. 193-200.

[93] Britta Wetzel, Rüdiger Pryss, Harald Baumeister, Johanna-Sophie Edler, Ana Sofia Oliveira Gonçalves, and Caroline Cohrdes. 2021. "How Come You Don't Call Me?" Smartphone Communication App Usage as an Indicator of Loneliness and Social Well-Being across the Adult Lifespan during the COVID-19 Pandemic. *International Journal of Environmental Research and Public Health*, **18**(12): p. 6212.

Received January 2022; revised April 2022; accepted August 2022.