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RESEARCH ARTICLE

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User experience and usability requirements of a physical activity smartphone application for wheelchair users with spinal cord injury

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ABSTRACT

Purpose: Usability considerations for wheelchair users remain underexplored. This study evaluated usability requirements of a smartphone App (MvBii) for monitoring physical activity and sedentary behaviour in manual wheelchair users with spinal cord injury (SCI).

Materials and methods: A mixed-methods design was adopted. Manual wheelchair users with SCI completed System Usability Scale, e-loyalty and user experience questionnaires, think-aloud sessions and scenario-based workshops. Six design and research evaluators undertook think-aloud sessions. Qualitative data was analysed thematically and mapped against heuristics.

Results: Ten participants with SCI (C5-L1; three females) with a mean age of 51 ± 9 years took part. The App received positive ratings on e-loyalty (mean scores, 5.6 ± 1.51 to 6.10 ± 0.99 across items) and user experience (4.3 ± 1.03 to 5.93 ± 0.78) from participants with SCI. A novel heuristics principle was developed to explore "accessibility and inclusion" usability issues. Thematic analysis captured patterned meanings across tasks and heuristics including "Navigating with autonomy" (e.g., challenges with interface clarity and understanding terminology), "Language and representation" (e.g., simplifying using inclusive language and icons), and "Seeing progress not noise" (e.g., physical activity notifications that encouraged self-competition without external pressure).

Conclusions: This study demonstrates the value of a mixed-methods approach to usability and heuristic evaluation for identifying effective, accessible and inclusive tailoring of physical activity Apps universally and for wheelchair users specifically. These findings can inform refinements to the MvBii app and provide broader insights for designing inclusive and effective mobile health Apps across diverse populations.

IMPLICATIONS FOR REHABILITATION

- Wheelchair users with spinal cord injury demonstrated high intention to use the physical activity smartphone App.
- Key usability issues were identified that should be considered in physical activity Apps include interface clarity, terminology, and visual accessibility.
- A novel heuristic principle was proposed that will aid in effective design for accessible digital experiences.
- Recommendations for physical Apps for wheelchair users include enhanced customisation, inclusivity and simplified language.

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User experience; user design; heuristic evaluation; physical activity; digital technology; wheelchair users; spinal cord injury

Introduction

Spinal cord injury (SCI) causes a loss of motor and sensory function across and below the level of the injury, resulting in individuals with SCI often using a wheelchair to support mobility. This population group generally engages in high volumes of sedentary behaviour and low physical activity, with 44% of individuals with SCI reporting that they do not engage in any moderate-to-vigorous physical activity whatsoever

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[1]. Increased sedentary behaviour and low physical activity are associated with higher risk of cardiovascular disease, which is one the leading causes of morbidity and mortality in individuals with SCI [2,3]. Wearable devices and smartphone technology provide a platform for delivering behavioural interventions in a convenient way at scale. These tools enable self-monitoring, goal setting and real-time feedback, which have been effective for reducing sedentary behaviour and increasing physical activity in non-disabled populations [4,5]. However, there is low availability of consumer-based wearables and smartphone Apps for tracking physical activity in wheelchair users, limiting intervention options in this population group.

Digital health interventions can enhance positive health-related lifestyle changes [6]. As digital health operates *via* the internet, it has the potential to have high reach and low costs per user [7,8]. Mobile health Apps focusing on health education and self-management, monitoring and prevention of complications, motivation and gamification for physical rehabilitation appear to be promising for individuals with SCI [9], especially as digital interventions help alleviate barriers related to transportation and the built environment [10]. However, effective use of digital health interventions is sub-optimal, with usage attrition (i.e., not using the intervention) and intervention attrition (i.e., loss of participants to follow-up) in individuals with chronic disease and SCI [8,9]. To optimise the usage of digital interventions, they should be designed taking into account the user experience i.e., what a person thinks and feels during and after exposure to the intervention [11,12]. This may help overcome issues around accessibility, technological complexity and motor impairments that individuals with SCI experience with mobile health Apps [9].

The User Experience Model integrates various theories and stipulates the underlying mechanism to the use of web-based interventions, therefore providing insights of how to enhance the user experience [11]. A good user experience positively enhances usage (referred to as "e-loyalty" in the model). The User Experience Model stipulates that intervention use is influenced by "efficiency" (the ease of the search and accessibility of the data), "effectiveness" (the quality/personal relevance of the information), "enjoyment" (the positive affective perceptions of the experience), trustworthiness (the believability of the information provided), and active trust (the assurance to be able to act upon the provided information) [13]. These constructs have a direct relationship to the usage of web-based interventions [13] and can, therefore, be utilised to enhance the engagement of individuals with SCI in App-based interventions. Yet, user experience models have scarcely been utilised to inform the development of physical activity Apps in individuals with SCI, limiting their usability and effectiveness for achieving behaviour change.

Heuristic evaluation assesses a product's user interface against established usability principles (heuristics) [14,15]. This inspection method has been employed previously for the evaluation and development of mobile health Apps [16,17]. However, there is an absence of literature identifying design and usability considerations for mobile health Apps in population groups with unique accessibility considerations, like wheelchair users with SCI. This may negatively affect user experience and reduce effectiveness of mobile health Apps in such population groups. Previous heuristics do not have clear standards relating to accessibility and inclusivity requirements [15,16], which may pose challenges to product development and adoption. Identifying general usability issues (i.e., Universal Design) alongside inclusive design aspects will support effective design of health Apps in general and inform specific tailoring appropriate for individuals with accessibility needs.

Consumer-based wearable and accompanying smartphone App technologies are widely available in the general population and are effective for supporting behaviour change [4]. However, there are limited options for wheelchair users and current wearables with a wheelchair user mode appear to be inaccurate in their measurement of physical activity [18]. The z-Track is a consumer-based wearable that has shown to provide valid estimates of physical activity and sedentary behaviour in wheelchair users with SCI [19]. The z-Track has an accompanying App, MvBii, that was originally designed for ambulatory individuals. As perceptions and needs may be specific to different populations, physical activity Apps should be evaluated in terms of universal relevance and accessibility-specific needs, which, in relevance to this study, will inform optimal design for wheelchair users.

Aims and objectives

The aim of this study was to evaluate user experiences and usability of a consumer-based physical activity smartphone App in manual wheelchair users and examine how usability issues relate to inclusivity

and broader principles of Universal Design. This will inform design of physical activity Apps that are effective universally and for individuals with accessibility needs. The objectives were to:

1. Identify system usability, e-loyalty, user experience and intentions to use the physical activity App with the target end users.
2. Identify usability problems experienced by end users and design and research professionals using think-aloud and heuristic evaluation.
3. Explore the need to include a novel focus on accessibility and inclusivity within heuristic evaluation.
4. Explore user requirements in relation to notifications, language, content and data visualisation that is appropriate and engaging for wheelchair users to support increases in physical activity and reductions in sedentary behaviour.

Materials and methods

This study adopted a mixed-methods approach to explore SCI-specific accessibility needs and Universal Design principles of the physical activity App, allowing identification of design features that create barriers for individuals living with SCI and a wider range of users. Usability testing [14,20] and heuristic evaluation [21] were undertaken with relevant stakeholders to provide a comprehensive evaluation of the MvBii App. Usability testing, such as the think-aloud method [22], involves observing real users interacting with a product to identify usability issues. This method was adopted to understand how stakeholders use the product, uncover pain points, and validate design decisions. While usability testing can be time-consuming and resource-intensive, it is a valuable tool for validating design choices and ensuring alignment with user needs. Embedded within the usability testing and heuristic evaluation, a creative approach was taken to catalyse conversations with target users to help identify usability challenges and design preferences. This involved "scenario-based study" [23] and "data visualisation" [24], adapted to understand participants' vision from existing to preferred state. To this end, such design tools helped derive value from creating a fictional context through stories.

About the MvBii App

The MvBii App (Glenworth Associates, Cambridge, UK) was evaluated for the purposes of exploring user requirements to enhance acceptability of physical activity Apps for wheelchair users. This App connects to a wearable device (z-Track) *via* Bluetooth, which was originally designed to support ambulatory individuals in tracking their physical activity. The MvBii App allows users to i) monitor sedentary behaviour, physical activity and energy expenditure, ii) set physical activity goals, iii) prompts/alerts to encourage regular physical activity and break up sedentary behaviour, and iv) send messages to friends.

The App presents day level and week level activity summaries for energy expenditure, activity time and periods of inactivity. The main content pages used in this study were Summary, Activity, Messages and Settings. The *Summary* page (Figure 1) shows the current day's physical activity totals and a share control for sending daily statistics to contacts. *Activity* displays a circular activity wheel with coloured dots that indicate intensity by time of day, a centre panel that shows total daily energy expenditure, and green arcs that indicate progress towards daily and weekly targets (Figure 1). *Messages* supports automated progress messages and one to one or group messaging with other MvBii users. *Settings* contains account information, goal setting for daily and weekly activity targets, parameters for inactivity alerts, a zoom control for the activity wheel and a link to a tutorial video. Functions such as remote camera control and music control exist in the App but were outside the scope of this evaluation.

Participants and recruitment

The study included two participant groups: i) manual wheelchair users with SCI (end users) and ii) designers and researchers in the field. Eligibility criteria for wheelchair users included female or male, aged 18–65 years old, complete or incomplete SCI, ≥ 1-year post-injury, used a manual wheelchair as the primary mode of mobility, able to fluently communicate in English, and able to travel to the data collection site. These participants were recruited through social media and from previous studies conducted

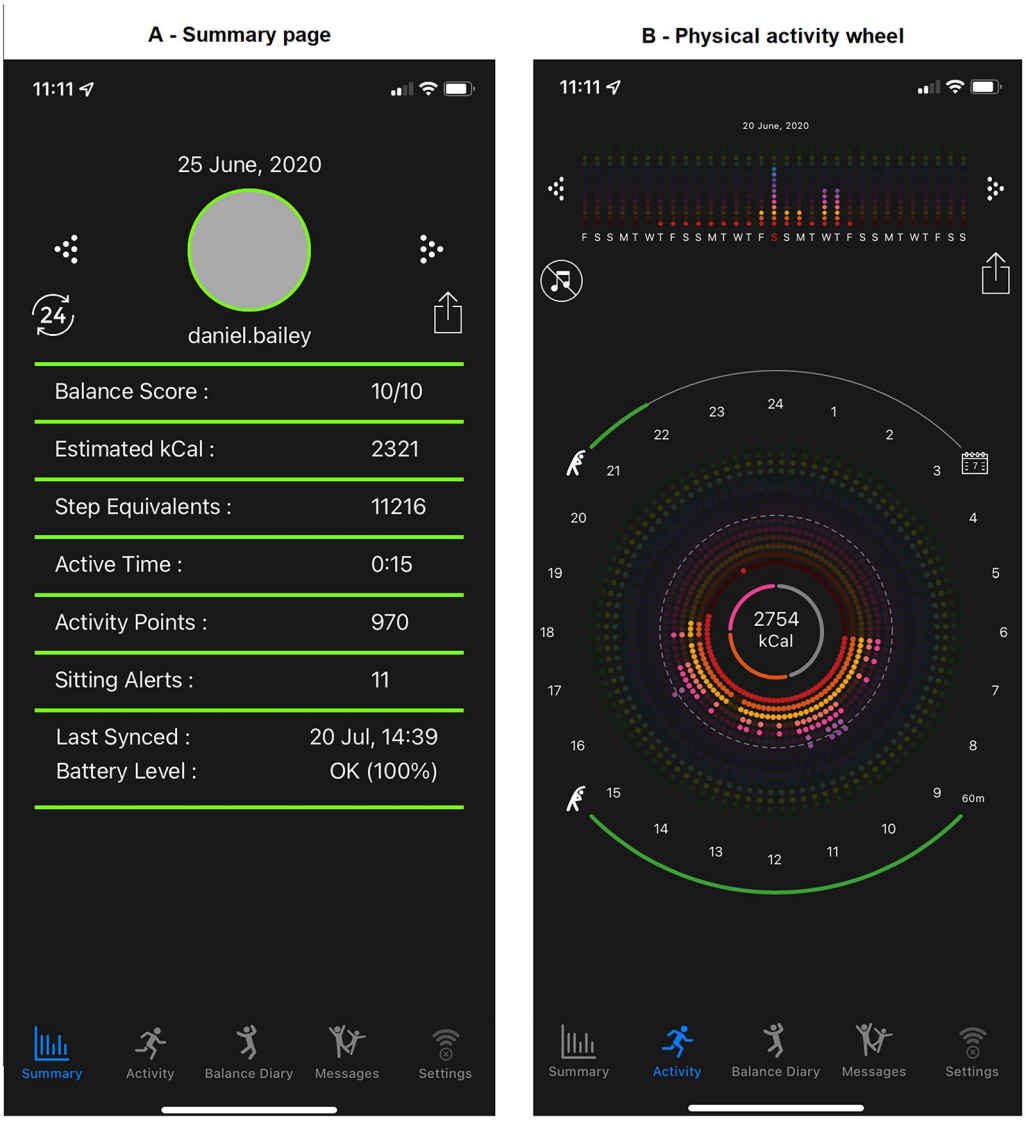

Figure 1. Summary page (a) and physical activity wheel page (b) of the MvBii App.

by the research team. Designers and researchers in health sciences ($n=6$) were recruited for the "heuristic evaluation" and were required to have academic and practical experience in their respective fields. The study received approval from Brunel University London Research Ethics Committee (reference: 35330-MHR-Mar/2022-38597-2) and all participants provided informed consent.

Data collection methods

The methods employed with end users to evaluate the App included (a) administering questionnaires to assess system usability, e-loyalty, user experience, and intention to use the App, (b) conducting individual think-aloud sessions to capture real-time user interactions and insights, and (c) using scenario-based activities and data visualisation techniques to explore user preferences and understand design needs. Research and design participantsxpert were asked to undertake a heuristic evaluation of the App.

Questionnaires

Participants completed the following questionnaires to evaluate system usability, user experience and intentions to use the App (see Supplementary Material 1). Each item used a 7-point Likert scale ranging from "Strongly disagree" to "Strongly agree" to evaluate the following constructs:

1. *System Usability Scale (SUS):* a 10-item questionnaire to provide a global subjective opinion of usability [20].
2. *E-loyalty:* assessed using three items that measured intention to use the App again in the future [11].
3. *User Experience:* assessed using four items that evaluated perceived efficiency, effectiveness, trustworthiness, enjoyment and active trust [11].
4. *Intention to use the App:* a single item derived from socio-cognitive models (e.g., Theory of Planned Behaviour and I-Change Model) to reflect the most proximal determinant of behaviour (e.g., adoption of an intervention) (25].

Think-aloud session

The think-aloud session was undertaken with participants performing a set of specified tasks as part of a scenario (Supplemental Material 2) on an individual basis [22] using simulated data already populated within the App. This method was employed to assess participants' reasoning and identify issues while using the App. A researcher read out the test scenario and then guided the participant through the tasks, using prompts where relevant to encourage depth in the data. Each individual session was audio recorded. Observations and field notes were also made by the researcher.

Scenario-based activity

Scenario-based activity with target end users were used to explore requirements related to App features, notifications, terminology and legibility of "data visualisation". Such creative engagement can elicit understanding around the perception of the functions and values of novel technology across participants [26]. The scenario-based activity was conducted in groups with the target end users. Participants were introduced to one scenario at a time (Supplemental Material 3) and following each, various prompt questions were asked to explore user requirements. The first scenario was used to understand requirements of pop-up notifications to prompt physical activity. Participants were presented with four different notification prototypes (Figure 2) and asked to discuss their opinions and preferences. The second scenario explored participants' views in relation to the App's current activity wheel design (Figure 1). To prompt discussions, participants were asked "What do you think the data is telling you?" and "How else would you like the data presented to you?". Additionally, discussions around "Step Equivalents" and "Sitting Alerts" took place to explore the relevance and changes of this language for the end user group.

Figure 2. Physical activity notification prototypes.

Heuristic evaluation

Heuristic evaluation was undertaken with research and design participants to identify usability problems with the user interface [14,15]. This involved evaluation of the App against a list of ten recognised usability principles, "heuristics" [15], and ensuring consideration of potential accessibility and inclusivity issues relevant to the target end users. The research and design participants were first asked to familiarise themselves with the MvBii App. They then undertook a predefined set of tasks within the App and completed a heuristic evaluation questionnaire (Supplementary Material 4), noting the usability problems they encountered related to each heuristic.

Data analysis

The SUS was scored by recoding each response to a score between "0" and "7," summing the odd number items minus 5 (x) and the even number items minus 25 (y), and then multiplying $x+y$ by 2.5, giving an overall score between 0 and 100 [20]. The mean SUS score was interpreted using validated thresholds [27]. Individual items for the e-loyalty, user experience and intention to use the App questionnaires were calculated as mean, standard deviation, median and interquartile range (IQR). IBM SPSS version 29.0 (SPSS Inc., Armonk, N.Y., USA) was used for statistical analysis. The analysis included calculating Cronbach's alpha to assess internal consistency of the questionnaire scales and evaluating differences in scores across user experience dimensions using Mann-Whitney U Tests. Statistical significance was set at $p<0.05$.

The think-aloud and scenario-based workshop sessions were audio recorded and transcribed verbatim. Data from these recordings was analysed thematically [28]. Codes were generated inductively while retaining heuristic tags as descriptive labels, then grouped into higher order themes and reviewed across the full data set. For the think-aloud session, usability issues were mapped to Nielsen's ten heuristics to guide the data interpretation, while themes from the scenario-based activity were organised with respect to each line of enquiry. For the heuristic evaluation with researchers and designers, data was categorised and analysed according to Nielsen's heuristics [29]. During coding, we observed recurring issues that may be experienced by users with accessibility needs, such as wheelchair users, not well described by Nielsen's ten heuristics. A novel 11th heuristic, "accessibility and inclusion", was developed to appropriately capture problems in this context. For each heuristic, a list of usability violations (coded deductively from the data) was created taking into account the issues identified by both the end users and research and design participants. Each of the study researchers ($n=4$) independently rated each usability problem for its severity (five-point Likert scale ranging from "0 – this is not a usability problem" to "4 – usability catastrophe, imperative to fix before product can be released") [29]. Usability issues rated ≥ 3 were considered "severe". Key usability issues were then mapped to Universal Design principles [30] with broader inclusive design and SCI-specific implications, where relevant, indicated as theorised by the research team. This was also undertaken for data in relation to nudge preferences and data visualisation evaluation.

Results

Sample characteristics

Ten manual wheelchair users with SCI ($n=3$ females) took part in the study. Their mean age was 51 ± 9 years, and SCI injury levels ranged from C5-L1.

System usability, e-loyalty, user experience and intention to use the app

The Efficiency scale had a Cronbach's alpha of .646, indicating acceptable reliability. The other scales demonstrated high internal consistency, including Effectiveness (α = .845), Enjoyment (α = .924), Active Trust (α = .877), and e-loyalty (α = .873). Based on the mean SUS score, the MvBii App had "high marginal acceptability" with an adjective rating of "OK" [27]. E-loyalty, user experience and intention to use the App were scored highly by participants. Descriptive statistics for these variables are presented in Table 1.

E-loyalty scores were compared between participants with high (Likert scale rating of 5–7; $n=8$) and low (Likert scale rating of 1–4; $n=2$) intentions to use the app. Participants with high intentions had a significantly higher median e-loyalty score compared to participants with low intentions (6.38 versus

Table 1. Descriptive statistics for system usability, e-loyalty, user experience and intention to use the app ($N = 10$).

Variable	M	SD	Median	IQR
System Usability Scale score	61.95	10.93	66.10	16.5
E-loyalty				
Visit this App again	6.00	1.25	6.50	1.00
Return to App	6.10	0.99	6.00	1.00
Recommend App	5.80	1.40	6.00	2.00
Recommend App for physical activity	5.60	1.51	6.50	3.00
Overall e-loyalty	5.88	1.11	6.38	1.81
User experience				
Efficiency	4.30	1.03	4.50	2.10
Effectiveness	5.75	0.86	6.00	1.60
Enjoyment	5.00	1.43	5.75	2.40
Active Trust	5.93	0.78	6.17	0.92
Intention to use the App	5.70	1.42	6.50	2.00

M = Mean, SD = standard deviation, IQR = Interquartile Range.

4.13, respectively, $U = 0.00$, $Z = -2.121$, $p = 0.034$), indicating that participants with higher intentions to use the App had greater e-loyalty. Participants in the high-intention group had a higher median SUS score (Median = 66.10; IQR = 16.1) compared to the low-intention group (Median = 51.75; IQR = 51.75), although this difference was not statistically significant ($U = 2.50$, $Z = -1.441$, $p = 0.178$).

Usability experiences and user requirements

A total of 52 usability issues were identified. Usability issues relevant to each heuristic with supporting quotations are shown in Table 2. The thematic analysis captured patterned meanings across tasks and heuristics: Theme 1 "*Navigating with autonomy*", Theme 2 "*Language and representation*", and Theme 3 "*Seeing progress not noise*". We retain traceability in the data by mapping issues to heuristic labels in Table 2 and design recommendations for effective nudges and user engagement in Table 6.

Theme 1 "Navigating with autonomy"

Participants wanted clear control, predictable navigation, and visible confirmation after making edits in the App. In relation to the heuristic principle "visibility of system status", participants identified that icons at the top of the Summary and Activity pages should better illustrate the current date and the ability to scroll between different dates: "There are some arrows at the top. I know that's the day, I'm just going through the days at the top. I took a second to work out what it did after I tried it." Being unable to navigate (i.e., pause, fast-forward, rewind and exit) the in-App video tutorial was an issue for "user control and freedom", which caused user frustration (the video also represented a severe "flexibility and efficiency of use" issue in relation to it being one single loop): "I'm unable to manually navigate or drag the video's progression." Another severe issue was the video tutorial audio only working *via* headphones, meaning issues of inaccessibility for users with hearing problems ("accessibility and inclusion"). One participant was unclear how to search for a new user or add a "new friend" when sending messages within the App ("user control and freedom"). As shown in Table 3, these usability issues infringed upon the Universal Design principles "Low Physical Effort", "Simple and Intuitive Use", "Flexibility in Use" and "Equitable Use" with both broader and SCI-specific implications.

Several "aesthetic and minimalist design" issues were identified (Table 2), but with only one of these being severe i.e., participants were unable to easily see the "plus" and "minus" icons that enable them to amend sitting alerts and daily activity targets due to poor background and icon colour contrast. This caused confusion for users until they tilted the device, which impacted the colours and made these icons more visible. Participants found this to be an issue of contrast and colour as the icons and background colour were difficult to distinguish at first glance:

> That could be maybe white, because it's a black background, black and grey background. These are very sort of, it's quite difficult to see that at first glance, I had to actually press the side to see if anything happened in it.

Table 2. Heuristics evaluation with identified elements.

Heuristic principle	Expert (n)	%	User (n)	%	Identified elements	Quotations supporting each element	Severity score (mean)
1. Visibility of system status	1	17%	0	0	The time out function of the App is too quick	"The time out function was very quick so ensuring this is adjusted to the user would be helpful as this could get frustrating" Expert ID	2
	1	17%	1	10%	System does not present confirmation of changes when activity target is amended	"Setting activity targets in the 'Settings screen'. Confirmation of changes would be helpful." Expert ID2 "At the bottom [of activity wheel], I've got something which says 60 min. The green bar at the bottom 60 min on that could be the goal and when I look in settings and try to change that to 120, then I go back to activity tab, has that changed? Yes, it's changed." User ID2	2.5
	2	34%	3	30%	System does not provide clear status of following elements regarding day and date at top of summary and activity pages: • Arrow icons do not clearly indicate ability to scroll through dates • No clear indication of current day and date • Unclear navigation of dates	"These kinds of arrows at the top formed by what is it, three, six dots, they toggle through the days. If I press the left one, I go to the second of August. Nothing there, but when I press the right one it looks like it's jumping by a month." User ID2 "In regard to the scrolling functions on summary a label of 'next' and 'previous' can be helpful as the arrows weren't clearly a scrolling function at first glance" Expert ID1	3
2. Match between system and real world	1	17%	2	20%	Messaging function does not match user's mental model of 'instant messaging' experience from across other Apps	"I thought that when you go into the messages, you'll be able to find the person you want to send a message to. I probably know that based on other Apps that I've used, that you're able to send messages directly to somebody by clicking on the arrow. It's not too dissimilar from an email." User ID3	2.75
	0	0	3	30%	'Active time' in 'summary' page is unclear to read – i.e., '00:00' does not contain indication of hours or minutes	"It doesn't say whether it's seven hours or seven minutes. It says, 'seven point 00'. It should be seven hours, but it should be more accurate because there could be many reasons that some people are not used to it." User ID6	2.75
	4	67%	8	80%	Difficulty setting 'sitting alerts' and 'daily activity target' due to wording discrepancies within 'my activity settings' in the 'settings page'	"I was not able to find where to set the sitting alert", "Many options setting items under My Activity Targets are confusing.", "Items under settings could be more effectively grouped for easier visual navigation and understanding" Expert ID4 "Doesn't specifically say 'sitting alerts… If you're looking to change something, it should specifically say 'sitting alerts." User ID5	3.5
	2	34%	4	40%	Function and meaning of 'activity prompt reset', 'activity prompt rest time' and 'activity prompt reset level' is unclear	"Activity Prompt Rest Time is unclear, is this my 'inactivity alert time'? Activity Prompt Reset time is unclear. Does this mean that the Prompt will time out after 5 min? I wasn't sure what the Activity Prompt Reset Level meant." Expert ID1 "I had to think about it. If there was a lead to manual to read, that will be fantastic. Just make things up as you go and see what happens like I did on the last one, because I still don't know what the activity prompt rest level will be." User ID6	3
	1	17%	0	0	Activity points, activity time, sitting alerts: expected to be found in 'activity page' in addition to 'summary page'	"When looking for activity points and time, I went to the Activity tab. But it turned out the info is under the 'summary tab'. I would prefer more intuitive and easy ways – e.g., more information could be provided at the 'activity tab'. This also applies to finding the number of sitting alerts" Expert ID4	1.75
	1	17%	4	40%	Expects icons in 'activity page' and 'summary page' to be clickable or interactive – i.e., dragging green arc to amend activity goal, tapping onto sitting alerts in summary page to amend **The following activity wheel content is too difficult to understand and unclear:**	"The summary page appears as buttons or links as may be expected on contemporary Apps." Expert ID2 "Some graphics appear like buttons" Expert ID2 "Calendar. I thought you can change that [clicks on calendar icon in activity tab]." User ID1	2.5

(*Continued*)

Table 2. Continued.

Heuristic principle	Expert (n)	%	User (n)	%	Identified elements	Quotations supporting each element	Severity score (mean)
	1	17%	1	10%	• Green arc in activity wheel visualisation	"I thought maybe that these bits of these green arcs might be the sort of waking part of the day, but it's not because it's nine o'clock at night till three in the morning." User ID2	3
	1	17%	1	10%	• Active person icons at top and base of activity wheel in activity page	"For the activity wheel the activity cartoons (icons) at the base and top of the wheel were unclear; in the video this is explained as daily activity and rest targets, but it looks like between the hours of 9am-3pm there is a target and between the hours of 9 pm-3am there is a target which is strange visually. I think two bars below the wheel labelled 'rest' and 'activity' would be better" Expert ID1	2.25
	5	84%	2	20%	• Colour dots in activity wheel visualisation	"I was anticipating an intro to the wheel chart under activity. It is not easy for me to understand. What do the different colours mean? What does each small dot mean? What does the "90 m" mean?" Expert ID4	3
	1	17%	3	30%	• '7' icon	"The icon with the number 7 is probably indicating the week, so I'm close to halfway of the target goal for that week, but the arc below the wheel shows that I completed 90 m. Is the upper one the weekly goal, while the lower is about the daily one? I couldn't tell." Expert ID5	3
	1	17%	2	20%	• '90m' and '60m'	"That says 60 M. I don't know what 60 M… I mean, I presume 60 min, but I'm not quite sure how that relates to anything else I'm seeing." User ID2	2.5
	1	17	1	10%	Data visualisation in 'activity wheel' page does not match typical reading direction, i.e., visualisation from left to right or vertical and horizontal axis	"I think the activity wheel could have some adaptations - rest and activity set as bars rather than around clock face and calorie colours clarified" Expert ID1 "If something goes up and down or left to right, it's an indicator that you're exerting that much more energy. If it's going up and you're exerting more (energy), if it's going down, you're exerting less. If it's going left then you're going down, if you're going right then it's going up. If it's in a circle, you don't know just by looking at it." User ID3	2
	0	0	1	10%	Lack of clear indication on format of time in 'activity wheel' page, i.e., 24-hour clock icon	"A 24-hour clock isn't it? When is it starting from, day time is from 12 o'clock at night? But there's nothing here, so it must have been, I don't know '60m' means whatever it says there, it says I've used 2339 calories but I can't see when they started and when they stopped because there's no hours." User ID1	2.5
	0	0	5	50%	User expects to bring up messaging function when selecting display photo of account holder in 'messages' page – function does not align with user's mental map	"I wanted to write a message, and I clicked on the face. I want to write a message in the form here." User ID1	2.5
3. User control and freedom	4	67%	0	0	Not able to navigate video tutorial manually: escape video, pause, forward and rewind video tutorial functions unavailable	"I'm unable to manually navigate or drag the video's progression" Expert ID4"Pause and rewind function needed on video guide" Expert ID1	3
	1	17%	0	0	Unable to amend daily activity targets in less than 15-minute intervals	"It would be helpful to have daily activity targets in 5-minute instead of 15-minute chunks" Expert ID6	2.5
	1	17%	0	0	Lack of ability to review or deselect participants when composing a group message in 'messages' page	"When sending messages, I would prefer a more efficient way to select recipients: if I want to select multiple contacts, there should be a review of all selected persons and I should be allowed to de-select. But in the current interaction, I have to redo the selection process again." Expert ID4	2.75
	0	0	1	10%	Users are unclear of how to search for new user or new 'friend' when sending message to individual parties	"I could send a message to [name of App account holder], I could send a message to the group. But I wouldn't know how to find a new person unless they'd already messaged me" User ID4	3

(*Continued*)

Table 2. Continued.

Heuristic principle	Expert (n)	%	User (n)	%	Identified elements	Quotations supporting each element	Severity score (mean)
4. Consistency and standards	1	17%	1	10%	In-app icons do not match user mental model	"Some icons do not align to some well-established mental models. Why "Setting" is a WIFI icon? "Message" is more like something denotes a "group". "Balance Diary" and "Activity" are quite similar." Expert ID4	3.25
	1	17%	0	0	Meaning of steps equivalent is unclear	"Step Equivalents - is this a metabolic equivalent of taking a step? It's unclear" Expert ID1	2
	2	34%	2	20%	Meaning of the word 'haptic' is unclear	"What are 'haptic activity prompts'? I've heard of haptic buttons because I have them on some smartphones." User ID8	2.25
	1	17%	6	60%	Meaning of 'activity points' is unclear and users unsure how points are accumulated	"Would have expected activity points to mean periods when I was doing exercise of some description. But it might mean data points. To do the exercise, I don't know, there seems to be quite a lot, a lot of them for it to be a duration." User ID2	3
	0	0	3	30%	Meaning of 'sitting alerts' is unclear and users not clear how alerts are generated	"Unless I actually went into another part of the App where it tells you what activity points mean what sitting alerts mean I wouldn't really know what the number six actually relates to." User ID7	3
	2	34%	2	20%	Function of share button to share 'daily stats' or activity wheel data with group or user is unclear (icon of square with arrow pointing up, at top right-hand corner in activity and summary pages)	"I didn't know what a share would result in" Expert ID 6	2
	1	17%	0	0	Function of 'activity wheel zoom' in 'settings page' is unclear and does not seem to elicit change	"I couldn't understand Activity Wheel Zoom (x2). Is it about zooming in to the activity wheel? Perhaps if it could be on the same page, then it would be easier to understand that since you can see the result after selection." Expert ID5	1.75
	0	0	2	20%	Unsure of the function of the arrow icon in the top right-hand corner of the messages page	"Speaker 1: So, we're in the messages tab and there's an arrow at the top right corner, but there's no indication of what that arrow means? Speaker 2: Correct." User ID3	2
5. Error prevention	3	50%	1	10%	System does not provide the following key functions in sent messages page:Message edit function • Message recall function • Ability to view messages thread • Ability to view individual sent messages	"When a message is sent by clicking the send button, I'm not able to see it in the "dialogue" view, only preview is enabled. I am not able to recall and re-edit the message. No way to recall sent messages." Expert ID4	3
6. Recognition rather than recall	0	0	3	30%	A lack of indication to help users recognise over what time or activity period calorie expenditure represents	"Speaker 2: Okay, so it's a Sunday so the activity time would be 324. Maybe 15 min and 24 s worth of activity. No, actually, because I'm looking at calories burnt, you can't burn 1852 calories in that space of time. So, it's more like three hours and 24 min' worth of activity." User ID3	3
	0	0	4	30%	User expects to find 'activity goal' information in main summary page	"Speaker 2: Just looking for something that tells me 'Activity goal'. Speaker 1: Would you expect it to be in the 'summary page'? Speaker 2: Yes. But I can't alter this… Speaker 1: You're tapping on the bits of information on the summary page and nothing's happening." User ID9	2.25
	1	17%	0	0	Not clear how long 'target duration' is for, or how the App functions once target is reached	"Target Duration may need further clarification. As far as I understand I set a daily target, and it is for either that week or that month. After that what happens? Will it go back to a standard or previous daily activity target?" Expert ID5	2
7. Flexibility and efficiency of use	1	17%	0	0	Ability to select birth year in settings currently inefficient for users – requires user to scroll manually to birth year in 'account settings'	"It takes a while to scroll to correct year of birth" Expert ID6	2
	2	34%	0	0	Inefficient function to scroll through days – top of summary and activity pages	"I would prefer a quicker way to navigate me to today rather than manually scrolling to the present date" Expert ID4	2.75
	1	17%	0	0	Video tutorial found to be inefficient as currently set to one single loop	"In the settings tab, suggest breaking the demo video up into different 'how to' videos for different issues rather than one video. You could also label them each so it's easier for the user. At present, there is only one long video on loop" Expert ID3	3

(*Continued*)

Table 2. Continued.

Heuristic principle	Expert (n)	%	User (n)	%	Identified elements	Quotations supporting each element	Severity score (mean)
8. Aesthetic and minimalist design	1	17%	0	0	Lines in summary page could be 'lighter and thinner'	"I would suggest that the dividing lines in the Summary tab to be lighter and thinner. They are distracting and cause visual fatigue - especially when set into bright and high saturation colours." Expert ID4	1.75
	0	0	2	20%	Unable to see all items in 'settings page', 'my activity targets' on full page view – users unable to see page scroll function clearly	"I'd want that smaller because I wouldn't know how to scroll up. So, everything I'm looking for is bam – on there (one full page). Or click another page to go on to another page? You know like a swipe. I never scroll up, which is my fault. But I didn't realise there was something down there." User ID1	2.25
	0	0	4	40%	Unable to see plus and minus icons in the settings page to amend sitting alerts and daily activity target	"There's a plus and minus and it's not highlighted. It's not very clear when I hold it up, and I'm looking at it head on. When it's flat on the table I can't see it at all." User ID3	3
	1	17%	0	0	User expects ability to personalise the App background	"I would like to change the background picture (Messages and Settings page)" Expert ID4	1
	1	17%	1	10%	Users consider 'emojis' in 'messages' page not to match mental map of emoji function in usual messaging	"I tapped on a list of 'stickies', I don't know whether they are kind of sticky messages that I can add." User ID2	1.5
	1	17%	0	0	Visual language of icons is inconsistent (colour scheme and the weights of graphic elements)	"The visual langue of icons is not consistent - both in terms of colour scheme and visual element weights." Expert ID4	1.75
	1	17%	0	0	Profile photo of the account holder in the messaging page is too large	"The way of shown pictures and my contacts' headshots need to improve. Too big for an elegant and beautiful interface." Expert ID4	1.25
9. Help users recognise and recover					N/A	N/A	
10. Help and documentation	1	17%	0	0	Video tutorials are too similar in content	"What are the differences between Video Tutorial and Watch Demon Video? They are quite similar." Expert ID4	2
	1	17%	0	0	Video tutorial is too slow	"The video I watched was simple but slow" Expert ID2	2
	1	17%	0	0	Lack of 'i' information icons that give more guidance or description of specific elements	"'i' buttons could be added to assist new users." Expert ID2	2
11. Accessibility and inclusion	3	50%	0	0	Expectation of more inclusive language and icons for wheelchair users – i.e., 'sitting alerts', active person icon	"Is 'sitting alerts' appropriate for wheelchair users - risk of causing offence and irrelevant content?" Expert ID6	3.75
	1	17%	0	0	More inclusive language in account set up to account for 'sex' and 'gender' in 'my account' settings	"Account: sex vs gender! Need to be careful with the word you use and provide choice, e.g., M, F, Other." Expert ID6	2.75
	1	17%	2	20%	Inability to adjust size of different elements, i.e., fonts; unable to easily click the arrow icons at top of 'summary' and 'activity' pages that provide date scroll function due to icon size	"Seems I am not able to adjust font size - many are too small for me, even on the iPad." Expert ID4) "Unless you've got stylus with on the phone like Samsung. Because we're talking about spinal injuries, with higher level of injury, the movements in the hands, and the finger is going to be limited." User ID6	2.75
	1	17%	0	0	Provide dark and light mode options for users with different visual requirements	"Seems only dark mode of the interface is available?" Expert ID4	1.25
	2	34%	0	0	Inaccessible audio for video tutorial – audio works only *via* headphones	"The video tutorial didn't have sound + it wasn't clear why gestures were included (I didn't know what a single shake would result in)" Expert ID6	3.75

Key: Severity scale scoring.

Severity scale				
0	1	2	3	4

0 – this is not a usability problem.
1 – cosmetic problem – need not be fixed unless time permits.
2 – minor usability problem.
3 – major usability problem, should be given priority.
4 – usability catastrophe – imperative to fix before product can be released.

Table 3. Mapping of severe usability issues, nudge preferences and data visualisation feature to universal design principles with broader inclusive and SCI-specific implications.

Severe usability issue / nudge preference / data visualisation feature	Universal Design principles implicated	Broader inclusive design implications	SCI-specific implications
Theme 1: Navigating with autonomy			
Difficulty selecting dates and navigating calendar views	Simple and Intuitive Use; Low Physical Effort	Increases cognitive and physical burden for all users	Repetitive fine-motor interactions may be frustrating and exhausting, reducing engagement
Video tutorial audio only accessible with headphones	Perceptible Information; Flexibility in Use; Equitable Use	Limits accessibility for users who cannot or prefer not to use audio	← As per broader inclusive design implications
Difficulty navigating video tutorial	Perceptible Information; Flexibility in Use; Equitable Use	Excludes users with diverse learning preferences	Reduces autonomy and increases frustration for wheelchair users with SCI, who may require additional time, repetition, or selective review due to fatigue, cognitive load, or motor effort
Unclear how to search for a new user or add a new friend in App messages	Simple and Intuitive Use; Flexibility in Use	Increases cognitive load and discourages social engagement	← As per broader inclusive design implications
Difficulty tapping plus/minus buttons due to small size and poor contrast	Perceptible Information; Low Physical Effort	Reduces usability for many users; accessibility issue for individuals with visual impairment	Increased physical effort and fatigue for users with limited hand function; higher likelihood of input errors
Unable to recall or edit messages or view messages in a thread	Tolerance for Error; Simple and Intuitive Use; Flexibility in Use	Impairs effective communication for all users	Increased cognitive load and frustration, particularly when interaction with the App requires sustained effort or precision
Theme 2: Language and representation			
Use of term "sitting alerts"	Equitable Use; Simple and Intuitive Use	Language assumes ambulatory norms, excluding diverse physical capabilities and experiences	Terminology may be irrelevant or alienating
Step-based framing of physical activity	Equitable Use; Flexibility in Use	May have limited relevance for individuals with different preferences and abilities	May feel invalid or demotivating for wheelchair users
Use of running person icon	Equitable Use; Perceptible Information	May limit broader identification and engagement	Reinforces perception that the App is not designed for wheelchair users
Use of complex or ambiguous terminology e.g., "activity points" and "sitting alerts"	Simple and Intuitive Use; Equitable Use	Reduced comprehension, trust, and effective engagement across diverse users and experience levels	May increase cognitive effort and reduce perceived relevance, particularly when terms are framed around ambulatory norms
Theme 3: Seeing progress not noise			
Preference for self-competition rather than social comparison	Flexibility in Use; Equitable Use	Choice in motivational strategies supports autonomy	Social comparison may be demotivating due to stigma or different ability levels
Frustration with "noise" from irrelevant notifications	Flexibility in Use	Customisable notifications would reduce alert fatigue for all users and improve sustained engagement	Alerts that feel irrelevant may be demotivating for wheelchair users with variable daily capacity
Confusion interpreting the activity wheel	Simple and Intuitive Use; Perceptible Information	Ambiguous feedback would reduce trust and sustained engagement	← As per broader inclusive design implications
Real-time feedback presented in engaging visual formats	Perceptible Information; Simple and Intuitive Use; Flexibility in Use	Enhanced motivation and usability for diverse users, supporting sustained engagement and behaviour change across populations	Increased motivation and comprehension, particularly where activity patterns differ from step-based norms
Need for a structured interface that allows customisation of visual elements to accommodate accessibility needs	Flexibility in Use; Low Physical Effort; Size and Space for Approach and Use	Adjustable interface elements and scalable touch targets improve usability for individuals with diverse motor abilities and device sizes	Difficulty to select accurately for individuals with limited hand function, increasing physical effort, frustration, and interaction errors

SCI, spinal cord injury.
Universal Design principles deemed relevant in the analysis included Equitable Use, Flexibility in Use, Simple and Intuitive Use, Perceptible Information, Tolerance for Error, and Low Physical Effort, Size and Space for Approach and Use.

These issues reduce usability for many users and may increase physical effort and input errors for SCI users with impaired hand function ("Perceptible Information" and "Low Physical Effort"; Table 3).

There were instances of icons within the App not matching user mental models. Severe "error prevention" issues related to the App's messaging function, including the system not providing message edit or

message recall ability. There was also an inability to view previously sent messages as a thread or view previous individually sent messages. Additionally, the system does not provide a confirmation notification that daily statistic or activity data has been shared successfully:

> I can't get back into it (message sent), doesn't seem to be a thread or is a thread here on this page assume that these were individual conversations, but they might just be up in one single place for all of your message messages to display.

Several Universal Design principles were infringed with respect to these issues and may have SCI-specific implications related to cognitive load and frustration (Table 3).

Theme 2 "Language and representation"

Wording and icons shaped whether the App felt made for wheelchair users. Participants emphasised that inclusive and precise terminology is essential to ensure users feel represented and engaged with the App. The term "sitting alerts" that may be relevant for non-disabled users did not align with lived experiences ("accessibility and inclusion"), with one participant noting "We don't need to be reminded that we're sitting. How would we change this? 'Get active' alert? I'm not sitting." (Table 2). Another elaborated on how the language implied an unnecessary distinction, stating, "The step equivalence isn't saying that you've been walking. But the sitting alert is kind of like it, we do that all the time, right? Assuming so, it's really talking about inactivity." The choice of words played a key role in motivation, with some participants advocating for a more positive approach. One participant suggested, "I'd prefer trying to flip it around to make it into something more positive. Maybe 'move alerts'."

Many existing Apps rely on step-based monitoring, which does not effectively translate for wheelchair users. Some found the concept frustrating

> I was talking with a friend a few weeks ago, and she's not in a wheelchair. She has one of the step counters and she said to me – "would that drive you insane? Being told how many steps you've taken?" And I said, yeah.

Others valued "step equivalence" as a comparative measure, with one participant noting, "I love step equivalent, it means I can be competitive with my able-bodied friends who use this measure." Others noted that the unit of measurement for physical activity within the App be reconsidered with alternative metrics, such as distance travelled or active time: "I got used to the steps, but perhaps, kilometres or miles would be better." The use of icons representing an ambulatory 'running' person icon across different pages would also need to be changed to a more suitable icon to represent wheelchair users ("accessibility and inclusion"): "Icons representing walking, running and jumping figures may not feel inclusive for wheelchair users. Different types of icons representing movement (may not include human figures) can be considered." The language and representation issues related to physical activity framing and sitting alerts demonstrate persistent "Equitable Use" infringements, which may lead to irrelevance across many user groups, especially wheelchair users (Table 3).

Aside from more inclusive language and icons, participants found some of the terminology in the App too complex or difficult to understand, referring specifically to "activity points" and "sitting alerts" in the Summary and Settings pages ("consistency and standards"): "It would probably maybe indicate lack of activity, or maybe not being as productive throughout the course of the time period that has been pre-set. I think sitting alerts will just indicate lack of activity." It was also difficult to understand phrases such as "activity prompt reset", "activity prompt rest time", and "activity prompt reset level", which are intended to set alerts in response to bouts of inactivity. This made it difficult to know how to set inactivity alerts ("match between system and real world"). Addressing the barriers would improve "Simple and Intuitive Use" across diverse users and increase relevance of the App for wheelchair users ("Equitable Use"; Table 3).

Theme 3 "seeing progress not noise"

Motivation improved when progress was simple to read and adjustable. The prompting nudge was seen as the most effective as it provided clear, straightforward feedback on progress, which would encourage users to work towards their goal (user requirements in relation to nudges to prompt physical activity are

Table 4. Preferences and feedback in relation to nudges to prompt physical activity.

Nudge type	Positive element	Negative element	Quotes
Confronting nudge	1. Direct and concise prompt 2. Prompts immediate action 3. Likely to prompt activity due to its straightforwardness 4. Does not require competition with others 5. Good for non-social users 6. Useful motivation for novice users 7. Useful for users who are already familiar and want to track physical activity 8. Quick and easy to understand	1. Some participants do not feel the need for constant motivation 2. Participants found this nudge can be easily ignored in unfavourable conditions, i.e., when user is distracted or too busy 3. Could be weather-dependent for wheelchair users, meaning they might dismiss this nudge altogether 4. Participants preferred having the option to turn this nudge off as it was suggested that over time this could cause frustration 5. Some participants found this type of notification can be intrusive	"I like that, it would work for me - just aimed specifically just at me. It's not competitive with anybody else, which can be good. It's just a 'right just get on and do it.'" "I think that will be most sort of likely for me to make do some because it's direct and to the point concise. That's probably one that would probably make me do something most." "I find these notifications quite annoying if they can't be turned off. If I needed motivation, then probably 'it's time to move' would help."
Social nudge	1. Can motivate those who are competitive or part of a group, particularly in social environments 2. Can compare progress with others, which is motivating for some 3. Can provide a record of user's physical activity data and therefore progress over time 4. Seen as beneficial for creating a supportive community, helping users to feel connected 5. Provides social accountability for users and encourages social interaction by celebrating or encouraging each other	1. Many participants found it guilt-inducing, irrelevant, or frustrating, particularly if they are not competitive 2. Social element brings a sense of expectation for participants to interact (social contract) 3. Most participants found they do not feel others' activities are relevant or motivating to them 4. Some participants mentioned feeling overwhelmed or disinterested in what others are doing 5. Users found the nudge can lack personal relevance 6. Participants find this nudge distracting or intrusive	"In terms of engaging in healthy competition, yes, it's quite good for competitive purposes. Someone finished it. I'll keep up with that." "Just because my friends completed steps, it wouldn't necessarily make me do it." "I think for me, I'm not too bothered about what anyone else is doing. Because everyone has their own target and goals."
Scarcity nudge	1. Works for individuals who appreciate gamification or competitive rewards such as points 2. Can provide positive reinforcement and competitive goal setting 3. Encourages a goal-oriented mindset for users who value tracking progress with clear milestones 4. Can be seen as helpful to reinforce routine with a visual element – for participants who benefit from seeing milestones	1. For some, medal or banner felt irrelevant or meaningless 2. Lack of real rewards or incentives makes it feel artificial, some would prefer something tangible like a voucher 3. Seen as lacking in personal connection as it did not seem to align with participant's intrinsic goals or values 4. Users preferred meaningful rewards	"It would only be useful if there was some kind of incentive that goes with the physical. You want a physical reward, not one that is artificial" "I don't think that will be very effective from my point of view. If it was money, maybe." "To win a pretend medal on a screen. There's nothing for me."
Prompting nudge	1. Preferred by participants as it appears when users are already active and encourages them to continue working towards their goal 2. Provides simple and quick visual feedback, which participants outlined helps them stay engaged and motivated 3. Works well for those who like tracking small goals and keeping themselves on target 4. Helps users set achievable goals, motivates them, and provides progress data that encourages action	1. Some participants did not find this nudge useful as frequent prompting was felt to be unnecessary if they are already self-motivated 2. Participants found it poses the risk of notifications being too frequent if they cannot be managed/customised (e.g., *via* settings) 3. Participants felt this notification could be less effective in low-motivation scenarios, i.e., when participants lacked in overall energy or motivation	"It'd be quite good, because if I'm out walking and I'm doing my steps, I've just got a little bit further to go. And I'll complete the whole task. I think it's a good little nudge to keep you going." "It would definitely engage me, because if you realise that, say for example, you're three quarters there, or that evidence, and you see exactly what you need to do to keep going." "For somebody that knows when they're going to train and they want to track their training, then you probably don't need it." "That's perfect for me. If I'm nearly at the end, if I see that I've got three miles to do, I will do the three miles after my gym and that's that finished for the day."

shown in Table 4). This notification made goals seem more attainable to participants. Users also felt that the prompting nudge would be valuable for supporting self-competition, helping them focus on meeting personal goals without external pressures.

The confronting nudge was considered moderately motivating for participants as it allows for a more self-directed approach compared with social nudges. This type of notification is direct and easy-to-understand at quick glance. Encouraging movement without pressuring the user to compete with others was seen as a positive element. Participants suggested increasing the font size to make the nudge quicker and easier to read, enhancing its usability in busy contexts. An option to customise the frequency of confronting nudges was seen as crucial for maintaining their effectiveness without becoming intrusive over time.

The scarcity nudge was also considered moderately motivating for participants, particularly among those who appreciated gamification and tangible rewards. The prospect of an award or points system appealed to users who valued external validation or friendly competition, with some finding it helpful in overcoming mental blocks. However, many participants were sceptical of accumulating points without a clear or realistic purpose, feeling that the "pretend" nature of virtual awards lacked in significance. There was a preference for realistic, meaningful achievements or goals, such as equating daily activity to "half a marathon," and the option to set personal, achievable challenges rather than accumulating points. On the other hand, participants suggested that tangible incentives would be more motivating.

The social nudge was generally considered the least effective. Most participants felt it created a sense of obligation to interact with others, often leading to negative emotions. While some appreciated the potential for "healthy competition", particularly among close friends or groups with similar goals, many felt the social nudge would be inappropriate due to varying physical targets and abilities between users. Participants understood the appeal of the social element but expressed that comparing themselves to others was often unmotivating, frustrating or guilt-inducing.

Nudge preferences were considered relevant to "Flexibility in Use", "Equitable Use" and "Simple and Intuitive Use" for broader inclusive design and specifically to individuals with SCI (Table 3). The design considerations identified here are important in the context of implementing features that are not demotivating to wheelchair users.

Elements of the activity wheel visualisation were difficult to understand. This included the green arc that indicates the amount of physical activity that has been completed for the week or month, coloured dots within the activity wheel that indicate physical activity intensity, and the "7" icon that indicates the 'weekly' physical activity goal ("match between system and real world"): "So what's confusing me a little bit is you've got these green arcs. And that, for me implies some kind of direction, some kind of time-based thing. But now I'm questioning whether that is time based." There was also difficulty recognising the timeframe or activity duration that the calorie expenditure data within the activity wheel of the Activity page represented, which was the only severe "recognition rather than recall" issue. Due to difficult in understanding the App's information, trust and engagement would be affected across different user groups (Table 3).

Participants highlighted the importance of data visualisation for their engagement with a physical activity App. They preferred simple, clear, and easily interpretable designs that provided immediate insights into activity levels, rather than cluttered dashboards that created cognitive overload. Adjustability in design elements, such as font size, colour contrast, and layout, was particularly important for accessibility, as some users had limited precision in hand and finger movements. Pairing terminology with meaningful visual cues was also considered essential for clarity. Participants suggested that icons representing wheelchair movement would reinforce the intended message behind alerts and notifications, making self-monitoring more intuitive and reducing misinterpretation. "For me, the picture doesn't mean that says social nudge, but it would be the icon of a person in a wheelchair pushing because that's what I'd be doing, medals mean nothing to me, but I see it as an end goal."

Real-time feedback was seen as an effective motivator, particularly when presented in an engaging format. Progress indicators, such as circular progress bars or colour-coded changes based on activity intensity, were preferred over static numerical displays. Immediate feedback on how close a user was to reaching their goal encouraged continued engagement. A structured interface that allows users to customise visual elements based on their accessibility needs was seen as critical to improving overall usability and supporting long-term interaction with the App.

Table 5. Design recommendations for enhancing usability and heuristic compliance across universal and SCI-specific users.

Principles	Key design recommendations
1.Visibility of system status	• Ensure functions do not time-out too quickly • Present user with confirmation of changes when 'activity target' is amended • Indicate clearly the current day and how to change to data visualisation for different dates
2. Match between system and real world	• Align the app's messaging function with user mental model, including icons, keyboard typing function, send button, messaging layout • Provide user with clear indication of the time frame that physical activity data is being presented in • Include activity points, activity time, and sedentary behaviour alerts in a summary page • Provide 'clickable' functions that permits users to amend information, e.g., such as progress details or goals and sedentary behaviour alerts, in a summary page • Ensure clarity in data visualisation, e.g., different coloured dots in an activity wheel indicating higher physical activity intensity • Provide ability to access messaging function when display photo of user is selected in other areas of the App
3. User control and freedom	• Allow user to navigate tutorial videos manually, i.e., escape, pause, forward and rewind • Enable user to amend daily activity targets in less than 15-minute intervals • Provide user ability to review or deselect participants when composing a group message within the App • Clearly indicate how to search for new users or new 'friends' when sending messages to other App users
4. Consistency and standards	• For wheelchair users, provide clarity or reword 'step equivalents' • Clarify the meaning of 'haptic', meaning and method of accumulating 'activity points', meaning of 'sitting alerts' and how they are generated • Ensure in-app icons match user mental models • Provide clear indication of how to share physical activity data
5. Error prevention	• Provide users with the following messaging functions: message edit, recall, ability to view message threads, ability to view individual sent messages
6. Recognition rather than recall	• Provide clear indication of the timeframe or activity duration that calorie expenditure relates to • Provide user with activity goal information in the summary page • Provide clear indication on the timeframe that displayed goals relate to
7. Flexibility and efficiency of use	• Provide ability to quickly and efficiently scroll through desired dated in relevant summary and activity pages • Shorter individual tutorial videos to make them efficient selection for the user
8. Aesthetic and minimalist design	• Provide clear visible function buttons to amend 'sitting [sedentary behaviour] alerts' and 'daily activity targets' • Provide users with ability to personalise App background • Provide familiar graphical elements, i.e., emojis, as additional features in messaging function • Provide a familiar size account holder photo as recognised in other Apps
9. Help users recognise and recover	• N/A
10. Help and documentation	• Create video tutorials that are clearly marked or separated (i.e., by topic) for ease of use and access • Increase pace or speed of video tutorial • Add 'i' button in areas within the App for user guidance and assistance
11. Accessibility and inclusion	• Use inclusive language and icons for wheelchair users • Use inclusive language in account set-up in relation to 'sex' and 'gender' • Provide ability to adjust / increase font and icon size • Provide dark and light mode options • Create accessible audio and video tutorials

> For someone with low hand function to click on those tiny days, that's going to be tricky. Unless you've got a stylus, it would be nice if you were able to expand the screen. We're talking about spinal injuries, higher level of injury, the movements in the hands, and the finger is going to be limited and won't be as accurate selecting items.

Design recommendations for enhanced usability, heuristic compliance and user engagement

Table 5 presents design recommendations derived from the heuristic evaluation, incorporating insights from usability experts and feedback from the think-aloud sessions with wheelchair users. These recommendations reflect a culmination of findings aimed at enhancing App usability, accessibility, and overall user experience. By addressing key heuristic principles and user needs, these recommendations will aid in designing physical activity Apps to support intuitive interaction, personalised settings, and inclusive design elements that best cater to users.

Table 6 outlines targeted design recommendations based on participant feedback for nudge type in addition to in-App terminology, means of reading data and data visualisation approaches. These insights reflect user preferences and needs, emphasising personalisation, accessibility, and effective motivational strategies. By incorporating these participant-driven recommendations, the design aims to

Table 6. Design recommendations for effective nudges and user engagement.

Design element	Key design recommendations
Notification design	• Offer users flexible notification frequency settings: options for daily, weekly or 'quiet mode' to reduce notification fatigue • Allow users to select or disable specific nudge types • Keep notification messages concise and simple • Offer users option to expand notification for more detail (detail on demand) • Provide accessible font sizing and simple language (especially in prompting nudge where clarity is crucial) • Enable users to select contacts or create groups to foster supportive competition, without feeling obligated to engage with all participants • Provide users with option to engage or disengage from social comparisons
Visualisation and accessibility	• Use inclusive terms like "active/inactive" instead of "sitting alerts" for better inclusivity • Replace "alerts" with "nudges" to reduce perceived pressure • Use quick visual indicators (i.e., countdowns, progress bars) to display activity progress at a quick glance • Ensure visualisations are accessible with contrast to accommodate colour-blind users • Provide different visualisation formats to allow users to select preference, i.e., circular, bar graph, simple progress icons • Simplify visualisations as much as possible • Provide users with quick visual access to activity data to lessen mental load
Personalisation and autonomy	• Offer users the option for a 'lazy day' so they receive fewer notifications, personalised to their unique daily routine • Include personalisation of font size • Offer an intuitive notification system to help reduce repetitive alerts

create an engaging, user-centred experience that aligns with diverse motivation styles and physical activity goals.

Discussion

This is the first study to investigate usability and heuristics of a physical activity App with wheelchair users. A mixed-methods design was adopted to yield an in-depth evaluation that would provide valuable insights regarding usability and user engagement considerations to inform the effective design of physical activity Apps for this population group and universally. Positive e-loyalty, user experience and intentions to use the App were reported, with high marginal acceptability for system usability. These findings demonstrate that the MvBii App has potential for user engagement but would benefit from improvements to enhance usability and effectiveness as a digital health intervention.

Findings indicated that users with higher intentions to use the App exhibit stronger e-loyalty, supporting the notion that behavioural intention plays a role in sustained engagement with digital interventions. This aligns with the Technology Acceptance Model, which posits that intention is influenced by constructs like perceived usefulness and ease of use [31]. Perhaps the concept of e-loyalty can also be understood within the framework of integrated socio-cognitive models, such as the I-Change Model [11,32]. In previous research, perceived ease of use predicted attitude, which in turn predicted intention to use a mobile App [33]. Another study showed that perceived usability predicted the behavioural intention to use amobile App [34]. The perceived usefulness, therefore, may align with the I-Change Model's conceptualisation of perceived advantages. This study underscores the interplay between usability concepts and constructs from integrated socio-cognitive models. Identification of how usability concepts sit within these models may help to understand how user engagement with physical activity Apps can be maintained [8]. To this end, implementing design features to increase behavioural intention should be considered in the development phase to promote sustained engagement.

The think-aloud and heuristic evaluation identified usability issues that can be addressed to improve usability of the MvBii App. Many of the issues are also likely to be generalisable to other physical activity Apps targeted for use by both wheelchair users and non-disabled individuals. When interpreted through the lens of Universal Design, several usability issues infringed upon core principles. Key usability considerations related to equitable use (e.g., language and visual representations that privilege ambulatory users), flexibility in use (e.g., limited personalisation of physical activity metrics, notifications and visual information), simple and intuitive use (e.g., unclear navigation and data presentation), perceptible information (e.g., small icons, poor colour contrast), and low physical effort (e.g., repetitive interactions and small touch targets). The broader inclusive design considerations can benefit all users, but their absence

may disproportionately affect wheelchair users with SCI due to impaired motor function, fatigue and irrelevant or alienating terminology or data visualisation. Addressing these issues will improve usability and better support behaviour change in wheelchair users and the general population.

With respect to specific usability issues identified, previous heuristic evaluations of mobile health Apps have identified problems similar to this study. For example, problems have included App buttons not following the expected mental map of the user, lack of identification of functions that the user could interact with, content not being detailed enough, and lack of confirmation by the App about what was happening after user interaction [35]. These problems may result in lack of trust in the system and ineffectiveness of the App to support behaviour change. The recommendations proposed in this paper will help to address common usability problems in mobile health Apps, including MvBii, that are designed to support increased physical activity and reductions in sedentary behaviour.

The need for a novel heuristic principle, "accessibility and inclusion", was identified to enable evaluation of usability issues that are unique to end users with accessibility considerations, such as wheelchair users. Previous evaluations of mobile health Apps for individuals with SCI have identified a need to assess usability problems relating to accessibility and inclusion [9]; the present study extends such research through assessment of issues in this context. The accessibility and inclusion principle was found to be important in the present study as it helped to identify severe usability issues, such as the need for more inclusive language (e.g., in place of "sitting alerts") and icons (e.g., in place of a running person), which are crucial for making physical activity Apps effective and relatable to wheelchair users. Physical activity Apps are, therefore, unlikely to be effective for wheelchair users unless they are tailored in accessible and inclusive ways. This aligns with the call that language and visual elements in user interfaces must be inclusive to ensure accessibility [36]. It is, therefore, recommended that "accessibility and inclusion" be included as a core principle when undertaking heuristic evaluations to capture special considerations across different end users and to make digital health technologies universally accessible.

Inclusive terminology and accessible data visualisation were found to be important for engaging wheelchair users with physical activity Apps. Participants found terms like "sitting alerts" misaligned with their experiences, as they framed inactivity negatively rather than encouraging movement. Instead, they preferred neutral or action-oriented alternatives like "inactivity alerts" or "move alerts," supporting research on the motivational impact of positively framed language [37]. Similarly, step-based tracking failed to accommodate alternative mobility patterns. Some valued "step equivalence" for comparability with non-disabled peers, while others preferred distance travelled or active time, reinforcing the need for customisable tracking options. Data visualisation also played a key role in engagement. Participants favoured clear, simple designs with immediate feedback, avoiding cluttered dashboards that create cognitive overload. Accessibility features like adjustable font size, contrast, and layout were essential, while wheelchair-specific icons and real-time progress indicators (e.g., circular trackers, colour-coded intensity levels) enhanced clarity and motivation. These findings align with research highlighting the value of personalised, context-aware activity tracking [37].

In addition to specific usability problems for wheelchair users that were associated with the new "accessibility and inclusion" heuristic principle, this study identified preferred technology mediated nudge types to prompt physical activity that are likely be universally acceptable. Building on previous research of technology-mediated nudging [38], the results of this study identified important considerations in relation to specific nudge types to enhance their effectiveness for behaviour change. Confronting nudges were effective for some users who need regular motivation for physical activity. However, confronting nudges were also seen as intrusive and frustrating over time. Social nudges motivate competitive users and foster community but can induce guilt and feel irrelevant to some. Scarcity nudges appeal to those who enjoy gamification but lack real rewards and personal relevance. Prompting nudges are favoured for encouraging active users and providing visual feedback, though they risk notification fatigue. These nudges should include personalised reminders, motivational messages, and adaptive goals tailored to the user's abilities and preferences. To enhance user engagement and effectiveness, this study emphasises the importance of i) addressing notification fatigue by reducing the frequency of notifications to prevent users from feeling overwhelmed, ii) providing information on demand by allowing users to access detailed information when they need it, rather than being bombarded with constant updates, and iii) user control over notifications, by giving users the ability to customise their notification settings,

including the type, frequency, and timing of alerts. By implementing these strategies, Apps and devices can better support wheelchair users in maintaining a physically active lifestyle.

A strength of this study was the mixed-methods design, allowing an in-depth understanding of usability and user experiences and how these relate to Universal Design and SCI-specific accessibility needs. Developing the new proposed "accessibility and inclusion" heuristic principle is a further strength as this enabled the study to capture usability issues that were uniquely relevant to the target end user group and more widely, where relevant, for non-disabled individuals. A potential limitation of this study is the absence of other important heuristics for evaluating mobile health Apps beyond those proposed by (15], such as "Navigation", "Privacy and security" and "User engagement". Thus, the present study may not have captured usability problems in the context of these principles as they were not included in the evaluation.

In conclusion, this study demonstrates the value of a mixed-methods approach to usability and heuristic evaluation for identifying important insights required for effective, accessible and inclusive tailoring of physical activity Apps in wheelchair users and the general population. Positive user experiences and marginal acceptability of the MvBii App were found. The usability issues and design recommendations can inform further development of the MvBii App and universal design of mobile health Apps to promote user engagement and effective digital health interventions in individuals with and without disabilities.

Author contributions

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Data availability statement

The quantitative datasets generated and/or analysed during the current study are available at https://doi.org/10.17633/rd.brunel.28524245.v1. The qualitative datasets generated and/or analysed during the current study are not publicly available because they contain information that could compromise participant privacy and/or consent.

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