Title: Evaluating the Usability of a Smartphone Virtual Seating Coach Application for Powered Wheelchair Users

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Abstract

The aim of the smartphone virtual seating coach (SVSC) was to provide a personalized reminder/warning system to encourage powered wheelchair users to use their powered seating functions (PSFs) as clinically recommended. This study evaluated the usability of the SVSC system by gathering feedback from five powered wheelchair users and five rehabilitation professionals through questionnaires and interviews. The results indicated that clear and understandable instructions to adjust the PSFs are the most important requirement for SVSC application. The instructions must be intuitive, could benefit from animations or indications of PSFs control buttons so powered wheelchair users can adjust their PSFs immediately and appropriately.

Powered Seating Functions

Abbreviations:

SVSC Smartphone Virtual Seating Coach

PSFs Powered Seating Functions

Powered seating functions (PSFs), which include tilt in space, backrest recline, and legrest elevation, are critical functions for people who stay in their powered wheelchairs for long periods.[1] Through altering tilt and recline angles, positioning mechanisms help people with limited trunk control maintain seating stability and to re-position their body.[2] Adjusting posture dynamically and maintaining proper postural alignment by using PSFs is important for managing complications such as orthostatic hypotension, autonomic dysreflexia, spasticity, and edema.[1] frequent and well-performed repositioning exercises can redistribute skin pressure, thus reducing the risk of developing pressure ulcers.[3] Appropriate seating adjustments may also improve driving safety. For example, using the tilt function to compensate for the changes in the center of gravity while driving on a slope may prevent the wheelchair from tipping over or the user from sliding out of the wheelchair.[1, 4]

The Virtual Seating Coach (VSC) provides a personalized system which can promote proper utilization of PSFs based on clinical recommendations.[5, 6] By comparing the seating function usage data with the clinical recommendations, the system provides tailored reminders to the users.[5] The VSC includes safety warnings, such as tilt angle adjustments while driving on slopes and repositioning reminders. Clinicians can customize the coaching program based on individual conditions, hence training can be extended beyond the clinical setting. Through individualized reminders proper usage of powered seating functions can be facilitated in their daily environment.

The Smartphone VSC (SVSC) was designed as an easily installed add-on system to be applied to powered wheelchairs with PSFs. In SVSC, accelerometers were connected to a microcontroller which converted the analog sensor signals into digital data and sent them to an Android smartphone. [7] [8] A Kalman filter was applied to decrease the noise. A smartphone cradle was designed to be easily mounted on the armrest of powered wheelchairs. The cradle allowed the users to position the smartphone based on their individual preferences to view the information displayed on the smartphone and operate their smartphones with greater ease. Our SVSC app has the ability to analyze the seating angle data and give users recommendations. (Figure 1) For example, when users are driving downhill on a steep ramp, the

app will remind the users to tilt the seat backward to improve sitting stability. The app shows the angle information as well as the target angle so the users can understand how to adjust their seating angles. The reminder display effects will change depending on how the users set up their smartphones' sound effects. [9] The purpose of this study was to test the usability of and gather feedback about the hardware and software designed for our SVSC system from powered wheelchair users and rehabilitation professionals.

Usability Study

Participants

The usability test of SVSC was performed with two groups of participants. One group was comprised of wheelchair users who had experience using PSFs. The other group consisted of rehabilitation professionals with experience in prescribing powered wheelchairs with powered seating functions, which included therapists, physicians, or engineers. According to a study that investigated the number of subjects needed for usability testing, 80 percent of usability problems can be detected by the first four or five subjects.[10] Therefore, five participants were recruited for each group in this study. The only criteria to recruit powered wheelchair users was to be 18 years or older and have the ability to operate a powered wheelchair equipped with powered seating functions as a primary means of mobility. All participants were required to have been using a smartphone more than one year so they understood how to operate most of the main functions of a smartphone, such as reading text messages, launching an app, etc. There were no exclusion criteria for either group of participants.

Protocol

This usability study was approved by the Institutional Review Board of the University of Pittsburgh. This study centered on the assessment of the usability of the SVSC via a questionnaire and an

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92 interview with open-ended questions. For the powered wheelchair users, the SVSC was installed on their
93 personal powered wheelchair. The researcher gave a brief introduction of the SVSC system including the
94 purpose of SVSC and an overview of the SVSC app. Participants were presented with two tasks: 1)
95 receive a repositioning reminder and adjust the seating angle following the instructions delivered by
96 SVSC and 2) receive a safety warning reminder and adjust the seating angle following the instructions
97 delivered by SVSC. In order to understand the users' preferences for the display layout and effects, the
98 repositioning and safety warning reminders were set differently. The repositioning reminder appeared on
99 the top of the screen (Figure 1A) and showed three choices ("OK", "Snooze" and "Cancel") for users to
100 decide if they wanted to perform the repositioning exercise. The safety warning reminders appeared as
101 text messages (Figures 1B and 1C). To check a safety warning reminder, the users needed to scroll down
102 the navigation bar and click the text message, which is the same way that most smartphone users check
103 their incoming text messages. The feedback messages for all of the reminders and warnings included a
104 short description about the reminder/warning and an angle bar indicating the recommended angle range of
105 the powered seating functions for users to adjust. The reminders/warning will not disappear if the users do
106 not follow the instruction to adjust their wheelchair, or follow the instruction incorrectly. After completing
107 these two tasks, the participants were given sufficient time to use the app and to ask any questions about
108 the SVSC system, and then were asked to fill out a questionnaire with a series of usability questions and
109 were interviewed to gather their feedback and opinions about the SVSC system. The rehabilitation
110 professionals were asked to complete the same two tasks as the powered wheelchair user group, and were
111 also asked to review the function of customizing the coach app, including the adjustability of settings for
112 safety warnings and repositioning exercise reminders. Afterward, they were asked to respond to the same
113 questionnaire and were also interviewed. All powered wheelchair users were encouraged to participate in
114 an in-home trial lasting up to five days. During the in-home trial, the SVSC system was on their powered
115 wheelchair all the time so the users could experience how the SVSC worked in their daily lives. This
116 could help determine if the SVSC would cause annoyance to the users or interfere with their daily

activities. After this in-home trial, all the participants were asked to answer the same questionnaire and interviewed to determine whether they had any additional feedback.

Questionnaire and Interview

A paper-based questionnaire was used to gather the participants' feedback, which collected demographic information, and included 24 questions about general impressions of the SVSC system. Five common usability[9, 11] components were included in the questionnaires: the visibility of the SVSC app; ease of use of the app; error prevention; and usefulness and satisfaction in terms of hardware and software.[12, 13] Users rated usability on a five point likert scale. Other questions asked which features of the SVSC system the participants liked most, whether the participants would use or recommend it to their friends to use if the system becomes commercial, and their impressions of the SVSC. Participants were interviewed to provide an open forum for discussing concerns or to provide suggestions with respect to the hardware and software of SVSC system.

Data Analysis

Principal component analysis (PCA) was used to test construct of usability questions. Descriptive analysis was performed to compare the differences in responses between the two visits of the powered wheelchair user group (PW visit 1 and PW visit 2) and rehabilitation professionals (Rehab Pro). The PC algorithm was performed to infer causal links with acyclic directed graph among different usability questions in the questionnaire from powered wheelchair users based on correlation test and the Spearman's rho was used to perform the correlation test.[14]

Results of Data Analysis

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Construct validation of questionnaire

The scree plot of the PCA (Figure 2) shows the presence of five factors with Eigen values > 1 , representing 90% of total variance in the index. Furthermore, after analyzing each question in each factor, most of the questions can be categorized in the five factors, which are visibility, ease of use, error prevention, usefulness and satisfaction. As a result, our questionnaire has the ability to gather the usability information from our participants in this study.

Visibility

Figure 3 shows the results about visibility from the powered wheelchair users and rehabilitation professionals. The powered wheelchair users and rehabilitation professionals in our study reported that the information was clearly delivered by the SVSC interface. The app provided statistical information for the compliance of performing the repositioning exercise and the number of safety warning reminders to the users. However, the statistics display of PSFs usage (clear stats chart display) and safety warning reminders (clear safety warning reminder for seat functions) were two items with lower scores for powered wheelchair users after the in-home trial. Our SVSC app used charts to present statistical changes, but the small smartphone display seemed to be not able to deliver the information clearly. The second issue of visibility was the safety warning reminders, which appeared as text messages. Some participants reported that the text message was too easy to ignore and they usually did not check the text messages. The navigation bar sometimes contained several icons of other different smartphone apps, leading to the fact that it would be harder to notice the reminders from the SVSC. For these reasons, having the reminders pop up on the screen would be a better way to remind powered wheelchair users to adjust seating angles. The rehabilitation professionals remarked about the small font size in our SVSC app. It was suggested that the SVSC should have font size options, or voice feedback messages/instructions for people with poor visual perception.

Ease of Use and Error Prevention

Figure 4 shows the results from the ease of use and error prevention analysis. The “easy to navigate the application” item received the lowest scores from both powered wheelchair users and rehabilitation professionals. Users were asked to perform different steps for repositioning reminders and safety warnings. For the safety warning reminders, the alert appeared as text messages. To check the reminders and enter the instruction screen, the users needed to click the text messages from the navigation bar. For the repositioning reminders, the alert came up on the screen, and the users could choose if they wanted to perform the repositioning exercise. Results showed most participants preferred the direct on-screen reminders; indicating the safety warning reminders required too many steps to access the instructions. Rehabilitation professionals noted that users with impaired fine motor function, might have challenges with accessing text messages. To reduce user error, the SVSC app automatically executes once the USB connection is made. SVSC is powered from the charging socket of the powered wheelchair. If the USB is not connected or the power jack is loose, the app will generate an error message indicating that there is a problem with the power connection. In our study, most of the users liked this design.

Usefulness and Satisfaction

Figure 5 shows results for usefulness and satisfaction. The usefulness ratings of the SVSC increased after the in-home trials for powered wheelchair users. Results indicate that intention to use the SVSC decreased after the in-home trial, but the powered wheelchair users tended to recommend the SVSC to other users. They reported already understanding the safety reminders and had a schedule to perform repositioning exercises. Rehabilitation professionals indicated that they would recommend the SVSC to their clients. The scores of the “sufficient functions and capabilities” item were low when compared to other items. Results indicate that the system needs to include a desktop software element or

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web-based dashboard to present a summary of PSF usage to review usage reports and adjust SVSC settings. Table 2 and Table 3 show the features of the SVSC participants preferred most and their concerns about the hardware/software from the questionnaire.

The SVSC implements selected coaching algorithms to remind users to use their PSFs appropriately. These coaching reminders are important clinical recommendations to prevent ineffective usage behaviors which may decrease sitting stability, result in tipping incidents, or induce complications due to prolonged static sitting. In our current design, the safety warning reminders kept reminding the users until they adjusted their seating angles appropriately. However, these coaching reminders might not be ideal in some situations. For example, when users are on the wheelchair, the system would remind them to have some minimal tilt angle to increase sitting stability. However, this warning reminder becomes inappropriate when the user wants to get close to a dining table with the height that can only accommodate the sitting position without being tilted. Another dilemma is legrest usage. When users elevate their legrests to a relatively large angle, it is recommended that they need to recline their backrest backward to prevent the over stretched hamstring muscles from rotating their pelvis posteriorly, causing a slouched posture in the wheelchair. This reminder, however, might not be suitable when they need legrest clearance to drive through places with obstacles where the mild tilt angle is not enough. To avoid continuously reminding users under these situations, the safety warning reminders need to have the option which allows the users to choose whether or not they should follow the recommendation to adjust their wheelchair based on their current situation. Another way to deal with this issue is using context awareness technology to determine the appropriateness of sending reminders to users.[5]

Causal Relationship from the Questionnaire

The causal relationship discovered by the PC algorithm showed that the instructions were understood to adjust the powered seating functions in response to the safety warnings ($r_s = 0.614, p = .02$) and repositioning reminders ($r_s = 0.624, p = .017$) were causes for powered wheelchair users to

recommend the application to other users. Participants would recommend the SVSC to other users if the instructions were very clear. In our current design, the SVSC provides an angle meter with target angle. Powered wheelchair users expected the reminders to tell them specific PSF(s) they needed to adjust, how they have to adjust them, and the reason that the PSFs need to be adjusted. Some users suggested that the instructions include the button for the PSF on the controller or having the animations of changing specific PSF.

Limitations

Conducting the usability test after presenting a working prototype to end users might limit some creative ideas from users about the application. Another limitation is that new powered wheelchair users were not recruited in this usability test. New powered wheelchair users may provide a different perspective. Small sample size might be an issue for the data representation of the target population. However, the idea of the usability study is to gather feedback from the end users and refine the development. All powered wheelchair users in this study had already used smartphones for more than 4 years. Using accelerometers to measure angle was unstable ($\pm 3^\circ$) while the wheelchair was moving, and the wires connecting the microcontroller to the accelerometers increased the width. The ideal design for the SVSC would minimize the wiring and/or use wireless data transmission.

Conclusion

This study tested the usability and gathered feedback from powered wheelchair users and rehabilitation professionals for further development of the SVSC system. The results from the usability tests provide information necessary to refine the SVSC system. Future development should provide more intuitive instructions to adjust PSFs in the SVSC app, reduce size and wires, and have an interface for rehabilitation professionals to review and tune the SVSC app.

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237 Conflicts of Interest

238 The authors (Y Wu, H Lui, J Pearlman, RA Cooper) wish to disclose that they are the inventors of the
 239 Seating Function Monitoring and Coaching System (US Patent Application 14/609, 747), which has been
 240 licensed by the University of Pittsburgh to Permobil, USA as the Virtual Seating Coach by Permobil,
 241 USA. The authors do not have any personal financial interest in Permobil, USA.

242

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246

247 Ethical Approval

248 Institutional Review Board of the University of Pittsburgh (PRO13010589).

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Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Table 1. The SVSC features that the participants liked (Question 2). ^a The coaching instruction is shown in Figure 1-3. ^b The repositioning exercise reminder is shown in Figure 1-2. ^c One rehabilitation likes the color of the whole smartphone app.

	PW Visit 1	PW Visit 2	Rehab Pro
▪ The seating angle information showed on the application	1	2	4
▪ Brief summary about the repositioning performance and the number of safety warnings	1	1	2
▪ The coaching instruction for repositioning and safety warning ^a	1	1	1
▪ The automatic repositioning exercise reminder ^b	5	3	3
▪ Customized setting for clients (If you are a clinician)	0	0	5
▪ Other	0	0	1 ^c

Table 2. The issues which are concerned by the participants (Question 3). ^a One rehabilitation professional suggest the whole system should have a dashboard for them to review the PSFs usage of wheelchair users.

	PW Visit 1	PW Visit 2	Rehab Pro
▪ The small display of a smartphone might not show the information clearly	0	0	3
▪ The location for the smartphone cradle might interfere with transfers or other daily activities	5	4	2
▪ The wires connecting the accelerometers might interfere with transfers or other daily activities	4	3	1
▪ The accelerometers might be damaged for long time usage	1	0	1
▪ Other	0	0	1 ^a