Emerging Technologies in Healthcare and Medicine, Vol. 116, 2023, 195–203
https://doi.org/10.54941/ahfe1004372

Enhancing Daily Posture Correction: Testing a Feedback-Based Assistive Technology for Individuals With Physical Disabilities

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ABSTRACT

Individuals with physical disabilities often maintain detrimental sitting postures due to paralysis, resulting in health issues such as pressure ulcers. This study introduces a pressure-sensitive sensor device for wheelchairs, assessing daily sitting positions and providing real-time feedback. Seventeen participants with disabilities underwent a 5-week trial, demonstrating positive effects on posture, secondary health problems, and physical function. While some outcomes lacked statistical significance due to individual differences and the study's duration, participant feedback emphasized the need for a mechanism to bridge the gap between perceived and correct posture. This research highlights the device's potential to enhance posture and well-being in disabled individuals, warranting further investigation.

Keywords: Feedback system, Physical disability, Seating, Posture, User testing

INTRODUCTION

Individuals with physical disabilities often spend extended periods in a seated position, making the maintenance of an appropriate sitting posture crucial (Nelham, 1981). Incorrect posture can lead to various complications, such as pressure ulcers, musculoskeletal issues like stiff shoulders and back pain, and imbalanced muscle conditions (Langford, 1994), ultimately impacting the ability to perform activities of daily living. To address these challenges, various methods called seating techniques have been proposed to correct sitting posture. For patients facing difficulties in supporting their upper body due to severe cerebral palsy or other conditions, some interventions involve securing the patient with a belt or similar device, under the guidance of healthcare professionals (Angsupaisal *et al.*, 2015; Kinose, 2017). Additionally, pressure-measuring devices, primarily used in hospitals, have been developed to ensure the proper dispersion of pressure when upper body support is possible (Ma *et al.*, 2017). Despite these advances, the focus on patients' posture in daily life remains limited, and there is currently no effective way to intervene in this area. Consequently, our study aims to fill this gap by testing a novel seating support device. The device utilizes a seat sensor integrated into a wheelchair, along with a feedback system, to promote improved sitting posture in daily life, the objective of which is to enhance physical function and reduce the risk of complications like pressure ulcers.

THE DEVICE

The device used in this study, developed in collaboration with the Universal Training Center, Inc. (UTC), consists of a seat mat with 32 pressure-sensitive sensors and a back mat with 16 pressure-sensitive sensors (see Figure 1 left). It also includes a data processing and communication device using LTE radio waves attached to the wheelchair's back, which estimates pressure values from each sensor and sends the data to the cloud. A smartphone application provides feedback to the user in three ways: a heatmap displaying seat pressure distribution (see Figure 1 middle), an icon display showing estimated upper body tilt (see Figure 1 right), and email alerts for postural tilt or high seat pressure. The heatmap displays 32 pressure-sensitive sensor values at a frequency of one measurement per second, with a resolution of 256 points achieved by spline completion (Peters, 1994). Shear stress on the seat surface is estimated from 16 points on the back surface, represented by directional arrows. The icon displays upper-body tilt when the pressure difference between left and right high-pressure points corresponding to the seat bones exceeds a certain threshold.

Figure 1: The seating assist device (left: appearance, middle: heatmap, right: icon).

Additionally, users can receive feedback from experts through an advice mail system, with a weekly message from a physiotherapist providing suggestions for improvement. There is also a 20-min remote rehabilitation conducted weekly via online meetings. In this rehabilitation, the physical therapist assesses the user's physical condition, reviews their week, suggests living improvements, provides instructions on decompression movements, and recommends exercises. This feedback, automated and human-led, is intended to reduce postural disorders and buttock pressure in daily life using seat sensor data (Sugawara, 2022, 2023).

METHODOLOGY

In this study, we conducted user tests to assess the effectiveness and enhancements of the device. Seventeen participants with physical disabilities, including spinal cord injury, cerebral palsy, and other impairments, were recruited based on the following three criteria: (1) Hoffer's sitting ability classification (Koga, 2009) 1 or 2, (2) no pressure ulcers within the past 6 months, and (3) at least 3 h of daily wheelchair use with the ability to attach the device to the wheelchair.

Ten participants utilized the device with feedback over a 5-week period, while seven participants engaged with the device without feedback. We compared pre- and post-intervention within the feedback group and between the feedback and non-feedback groups using a reach test to assess physical function, a questionnaire to investigate internal symptoms and changes in attitudes toward posture, and posture estimates using this device to evaluate sitting posture. In addition, a group interview was conducted to ask about areas for improvement. The reach test (Duncan, 1990) involved participants assuming a sitting posture and measuring the forward, right, and left extensions from the basic position. This test assessed physical abilities such as balance and shoulder joint range of motion. A physiotherapist (co-author 3) closely monitored the test, correcting any mistakes and ensuring safety. Five-point Likert scale questionnaires were conducted at the beginning and end of the user test, investigating introspection of secondary disabilities, postural awareness (see Table 1), and the usage of feedback. To analyze the results of the reach test and questionnaire, the statistical significance of differences was assessed using Wilcoxon's signed rank test (two-sided, 5% level, small sample) for pre- and post-intervention comparisons and Mann–Whitney's U-test (two-sided, 5% level, small sample) for comparisons between the feedback and non-feedback groups. For evaluating sitting posture, participants were asked to assume an ideal posture for 10 s, and the deviation of left-right pressure ratio during this time was recorded. We used Equation 1 to determine whether the deviation of the right half of the seat pressure decreased from before to after the intervention, indicating any postural improvement. Finally, we conducted semi-structured interviews with seven members of the feedback group who consented to participate. These interviews focused on device usability, the fit with their experience, postural improvements, and device-related suggestions. The interviews were conducted in group format with the subjects at each measurement session. By employing these methodologies, we aimed to comprehensively assess the device's effectiveness and gather valuable insights into its impact on users with physical disabilities.

Table 1. Sample questions of five-point Likert scale questionnaires.

Questions about introspection of secondary disabilities and troubles	Q1. Do you feel anxious about bedsores? Q2. Do you feel hunched over daily? Q3. Do you experience a decreased range of motion of the shoulder joints? Q4. Do you feel stiff in the shoulders? Q5. Do you feel muscle tension or stiffness? Q6. Do you experience a decreased lung capacity? Q7. Do you feel that you are gaining weight (becoming obese)? Q8. Do you tire easily in daily life?
Questions about postural awareness	Q9. Is a correct posture important in your life? Q10. Do you feel that a correct posture and health are connected? Q11. Are you satisfied with the current measures to improve your posture? Q12. Do you feel able to sit correctly in a wheelchair? Q13. Are you aware of the need to maintain a correct posture on a regular basis?

$$y = \left| \frac{W_{right}}{W_{right} + W_{left}} - 0.5 \right|_{after} - \left| \frac{W_{right}}{W_{right} + W_{left}} - 0.5 \right|_{before} \quad (1)$$

RESULT

The results of the user test are presented below. One participant from the feedback group was excluded from the analysis due to a 2-week hospitalization during the study.

Seated Balance

Change in seated balance was estimated from the seat sensor pressure distribution. If the value defined in Equation 1 is negative, there is an improvement trend, and if the value is positive, there is a worsening trend. However, if the absolute value is small (less than 0.01), it was decided that this would be considered to reflect no clear change. In the feedback group, improvement in this regard was shown in 4 out of 8 cases, with 2 cases showing no clear change and 2 cases worsening. In the non-feedback group, 5 out of 7 cases demonstrated worsening balance, and 2 cases showed no clear change. The comparison indicates that the intervention might bring patients closer to the correct posture.

Reach Test

The forward, rightward, and leftward reach test results before and after the user test are shown in Figure 2 for the feedback and non-feedback groups. The feedback group demonstrated improved mean reach distances in all directions, while the non-feedback group showed slight increases or decreases in mean reach distances. However, no significant differences were observed for forward and left directions of the feedback group or in comparisons between feedback and non-feedback groups.

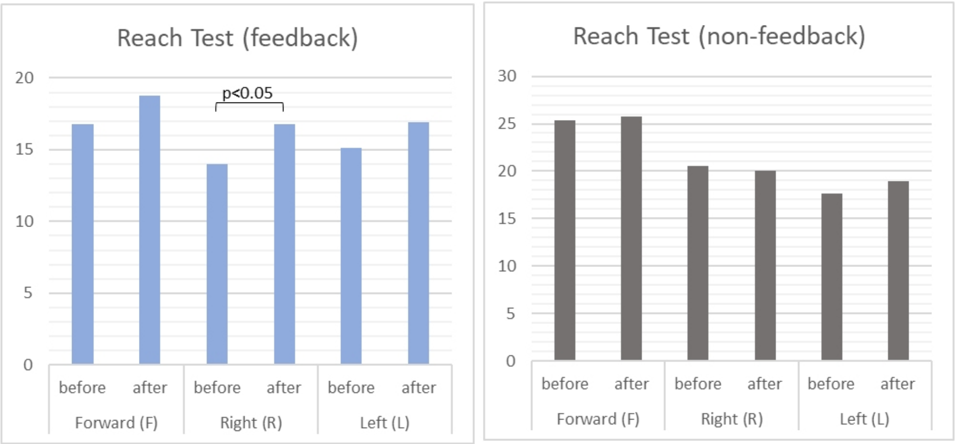

Figure 2: Results of reach test (left: feedback group, right: non-feedback group).

Questionnaire Results (Introspection, Posture Awareness)

Figures 3 and 4 show the average scores for the questions on introspection and attitude awareness. The questionnaire survey revealed only two statistically significant differences in pre- and post-intervention within the feedback group and between the feedback and non-feedback groups: a decrease in the mean score for Q3 ("Do you experience a decreased range of motion of the shoulder joints?") after the intervention and an increase in the mean score for Q11 ("Are you satisfied with the current measures to improve your posture?").

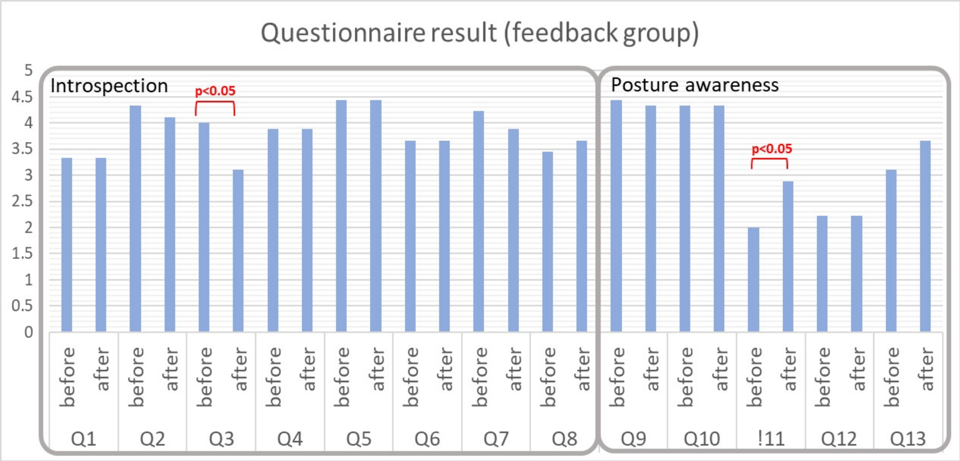

Figure 3: Questionnaire results of the feedback group.

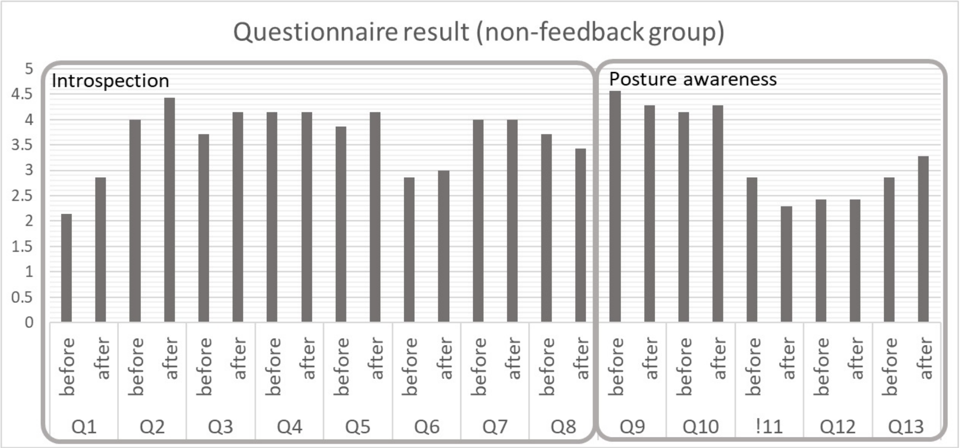

Figure 4: Questionnaire results of the non-feedback group.

Questionnaire Results (Utilization of Each Type of Feedback)

Participants rated their ability to understand their posture, identify areas for improvement, and improve their posture using four feedback methods: remote rehabilitation, icon display, alert, and heatmap display. Although the scores for each item did not differ significantly, remote rehabilitation heatmap feedback appeared to be utilized more than icon alert feedback.

Table 2. Mean of five-point likert scale questionnaires about utilization of each type of feedback.

	Remote rehabilitation	Icon display	Alert	Heat-map
I was able to understand the posture	4.2	3.9	3.8	4
I was able to understand the improvement of my posture	4.2	3.8	3.8	4.1
I improved my posture	3.9	3.4	3.7	4

Group Interview Results

In the interviews conducted with the feedback group, participants expressed views on discrepancies between the feedback and their introspection, the absence of such discrepancies, and potential improvements to the system. Table 3 provides excerpts of these findings.

Table 3. Excerpts from interviews with the feedback group.

Whether feedback was helpful in improving posture	
	There was no discrepancy between the heat map feedback and the introspection. I tend to lean to the right and my right side hurts more. The heat map also showed that I lean to the right, which made me think that I should pay attention to it.
	There was a discrepancy between the feedback on the icons and introspection. The icons on the display always showed a " nice posture" even when there was no way to be
	The "arrows" on the heat map were displayed. When I tried to correct the posture by myself, I was forced to do so and ended up in a strange position. However, the remote rehearsal pointed out to me exactly how to improve my posture, and I found a stable
Improvement (hardware)	
	It was inconvenient to fold the wheelchair because the seat was difficult to maneuver.
	The cord sometimes came loose. The cord could not be reinserted by oneself.
	The seat is only a few millimeters thick, but it is very uncomfortable. My back hurt.
Improvements (software)	
	During work, I'm inevitably distracted from my posture. It would be better if the information is displayed in a place where I can easily see it, such as on my desk.
	I don't notice notifications easily if they are sent by e-mail.

DISCUSSION

Based on the results of a 5-week user test, while only some parameters showed statistically significant differences, positive impacts of the introduction of this device on seated balance, physical function, and introspective symptoms were suggested. The primary goal of the feedback, both automated and human-led, was to directly improve seated posture. The seated balance metric defined in Equation 1 pertained to whether a user sat in an even position on the wheelchair seat and ensured that the body's center of gravity was not shifted due to the upper body tilting. In the non-feedback group, none of the subjects showed improvement, whereas in the feedback group, half showed improvement, suggesting that feedback could promote correct posture. Further, an improvement in seated posture was anticipated to result in enhanced physical function. The reach test results are said to relate to seated balance capabilities and the shoulders' range of motion. In the feedback group, there was a trend of increased distances in each direction in this test, suggesting potential improvement in these physical functions. The large p-value regarding this trend might have been due to the diverse physical and living conditions of the disabled participants, resulting in high variance relative to the sample size. For more scientific evidence, further research with a larger sample size is needed. Lastly, preventing or mitigating secondary health problems was also expected from improving the seated posture. Statistically significant differences were observed only in the shoulder joint, as shown in Figures 3 and 4. This might be more influenced by remote rehabilitation training guidance than feedback on daily seated posture. In fact, during the interviews, positive opinions about remote training guidance were offered. No significant differences were found in other introspective symptoms. The large p-value might have been due to the diverse conditions of the disabled participants and the delayed onset of secondary impairments, making it difficult to see effects within the 5-week study period. Upon closer examination of the graphs, the non-feedback group was more concerned about bedsores, stooped posture, and muscle tension before and after the user test. This might have been due to a change in seat conditions, even though feedback was not provided, and the sensor mat was installed, possibly raising concerns about bedsores. Discomfort with the seat sheet was also mentioned in interviews. Additionally, guidance on secondary health problems such as bedsores, stooped posture, and muscle tension was provided during the user test, which might have increased concerns about these particular issues. However, in the feedback group, introspective symptoms had not deteriorated as much, suggesting that measures like pressure relief actions and expert advice might have alleviated their concerns. In conclusion, although further verification is required, this study found clear positive effects of the prepared automated and human-led feedback.

Next, we discuss the characteristics of each type of feedback that we provided. Our initial hypothesis posited that users would find it challenging to visualize their upper-body posture using only heatmaps derived from seat sensor data. Hence, additional feedback mechanisms like icons and alerts were incorporated. However, the survey and interview results showed that users preferred interpreting the heatmap to understand and reflect on their posture. This preference might be attributable to three potential shortcomings of icons and alerts when compared with heatmaps. The first is the issue of threshold values. While heatmaps display data without thresholds, icons and alerts only present information when a specific threshold is surpassed. Feedback from the interviewees indicated that, even if their upper body tilted to the right, an icon might still indicate a proper posture. Such a discrepancy between the feedback and users' perception of their posture could hinder posture improvement. Setting a universal threshold for individuals with physical disabilities could be challenging. Second, there is a time lag problem. Icons and alerts have a slower update frequency, causing a delay in reflecting posture changes. In contrast, heatmaps display almost in real time, with a lag of about 4 s. Immediate feedback about incorrect posture is crucial for making timely adjustments. The third shortcoming is related to the fidelity of information. High-fidelity data can overwhelm users, making it hard to discern essential details. However, fidelity that is too low prevents the pinpointing of specific issues. The icons and alerts used in our study, for instance, had low fidelity, lacking precise direction and degree of posture improvement. Considering these factors, it is plausible that users found heatmaps more beneficial than icons or alerts.

However, this study highlighted the insufficiency of relying solely on heatmaps for posture improvement, emphasizing the pivotal role of human feedback. Interviews revealed that, when attempting to rectify posture by referencing heatmaps, participants often adopted unnatural postures. However, remote rehabilitation provided precise guidance, allowing them to make appropriate adjustments. Deriving a three-dimensional understanding of the upper body from the two-dimensional information of heatmaps and then discerning the deviation from the ideal posture is challenging, likely necessitating expert advice. However, it is impractical for every individual with physical disabilities to consistently seek professional guidance. Therefore, future research should explore novel feedback mechanisms, such as displaying the user's current posture and the ideal posture in a three-dimensional avatar form, making it easier to discern discrepancies. Moreover, feedback that integrates into daily routines is crucial. Multiple interviewees indicated the challenge of consistently monitoring posture-improvement notifications amidst daily tasks like working or housekeeping. This underscores the need for innovative solutions to incorporate feedback mechanisms into regular routines.

CONCLUSION

This study suggested that automated and expert feedback concerning everyday posture has the potential to positively influence posture adjustments, reduce the risk of secondary complications, and enhance physical function. Furthermore, there is an implied need for a feedback mechanism that accurately depicts the current upper-body posture in real time and three dimensions.

LIMITATIONS

The limitations of this study include a small sample size, a short research period of approximately 5 weeks, which may not be sufficient to observe changes in physical function or secondary complications, varying degrees of disabilities among the participants, and inconsistent shapes of the wheelchairs and mats used. Additionally, the duration of wheelchair usage in daily life varied among the participants, and issues such as equipment cords becoming unplugged also occurred. To achieve results with higher scientific validity, there is a need for more stringent screening criteria, a larger group of subjects, and longer user testing durations.

ACKNOWLEDGMENT

This work was supported by JST SPRING, Grant Number JPMJSP2106. The authors thank all those who participated in the study and members of Tokyo Institute of Technology's Saijo laboratory. This work utilized OpenAI's ChatGPT for initial drafting, which was thoroughly reviewed, edited, and supplemented by the authors. We therefore assume full responsibility for the final content of this publication.

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