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Paper:

Skill Abstraction of Physical Therapists in Hemiplegia Patient Rehabilitation Using a Walking Assist Robot

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Improving the walking functions of hemiplegia patients after a stroke or brain injury is an important rehabilitation challenge. Recently, walking assist robots have been introduced in advanced rehabilitation facilities as a way to improve the efficiency of patient rehabilitation and restore their walking functions. Expert therapists can apply this device on different patients; however, such application mainly depends on the therapist's tacit knowledge. Thus, it is often harder for novice therapists to apply such devices on different types of patients. Consequently, effective use of a walking assist robot has become a new patient rehabilitation skill. Taking rehabilitation as a service provided by medical doctors or therapists to their patients, this study aims to improve the quality of the rehabilitation service. In particular, the objective of this study is to abstract the rehabilitation skill of expert therapists in using a walking assist robot by applying a service science methodology known as skill education. Skill abstraction was performed by interviewing an expert therapist. From this interview, it was found that the expert therapist classified hemiplegia patients into four different classes. Using videos of patients walking, further analysis revealed the expert's tacit knowledge, which was indicated by differences observed among these four groups in particular phases of the patients' walking patterns. This study shows that by successfully obtaining explicit knowledge of part of a rehabilitation skill by using a walking assist robot (which until now was a tacit knowledge of experts), and then organizing the acquired explicit knowledge, even non-experts can easily reproduce the skill of experts in new patient rehabilitation.

Keywords: skill education, walking assist robot, rehabilitation, hemiplegia

1. Introduction

Restoring or improving the walking functions of patients with hemiplegia after a stroke or brain injury is an important rehabilitation challenge. With an aging society, the hemiplegic population has increased. Recently, walking assist robots have been introduced in advanced rehabilitation facilities as a way to improve the efficiency of patient rehabilitation and restore their walking functions [1–8]. The introduction of a walking assist robot allows the application of an external force with unrestricted timing during walking, thereby permitting a more effective restoration of walking functions.

However, with only a few cases based on usage experience, new rehabilitation programs suited to different patients have not been established [9, 10]. As a result, it has been noted that, even in facilities that have been introduced to walking assist robots, the staff is unable to effectively apply these devices on patients due to inexperience. Furthermore, locomotion abilities differ among patients depending on their extent of brain damage following a stroke or the stage of their recovery process [11, 12]. Thus, for hemiplegia patients, it is necessary to determine how to apply the walking assist robot to every individual patient in order to maximize the value delivered by the new robotic rehabilitation.

From the perspective of service engineering, rehabilitation is a service provided by medical doctors or therapists to their patients. Through different training programs, a walking assist robot can provide appropriate treatment for different individual patients. However, if therapists cannot determine which patients are suitable for which rehabilitation program, the walking assist device cannot be effective in fully improving the patients' body functions. This study examines a rehabilitation method that uses a walking assist robot as a new rehabilitation skill. By applying a service science methodology known as skill education, the quality and efficiency of rehabilitation can be improved. This methodology is shown in **Fig. 1**.

Skill education is important in promoting the use of the

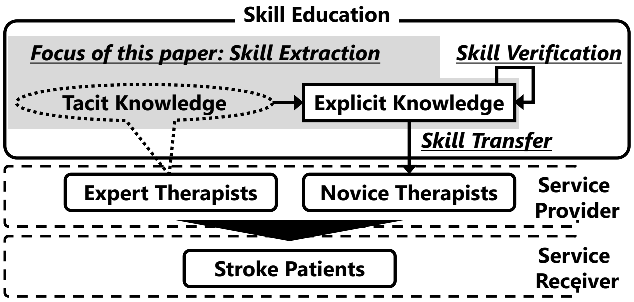


Fig. 1. In rehabilitation, therapists are considered as the service providers, whereas stroke patients are the service receivers. To improve the quality of service, it is important to derive explicit knowledge from the tacit knowledge of the expert therapists and transfer this knowledge to novice therapists through skill education. This paper focuses on skill extraction from the tacit knowledge of expert therapists.

walking assist robot in rehabilitation therapy. As identified in a study by Nakagawa et al. [13], skill education can be divided into three processes: skill extraction, skill verification, and skill transfer.

- Skill extraction is the abstraction (or extraction) of the tacit knowledge (skill) of the expert into explicit knowledge.
- Skill verification is the evaluation of the extracted skill and verification that the skill is useful.
- Skill transfer is the explicit expression of the extracted skill in such a way that novices can utilize the knowledge.

This paper focuses on skill extraction only. Using their tacit knowledge, expert therapists can implicitly classify patients and determine the appropriate rehabilitation for individual patients with different impaired movements. Our first aim in this study is to clarify this tacit knowledge by interviewing the expert therapists and examining videos of walking patients. Next, we will develop a new methodology for classification of patients such that novice therapists can identify different types of patients based on videos. These two steps constitute the skill education that will enable novice therapists to learn how to use a walking assist robot.

2. Skill Extraction Through Interviews

2.1. Methods of Skill Extraction from Interview

For this study, a hemiplegia patient was provided walking rehabilitation using a Honda Walking Assist robot. The basic mechanism and control scheme could be found in [14]. This robot is attached to the waist of the patient and generates torque in the coxa at optimal times during walking. This robot is composed of three parts: a waist frame, a thigh frame, and an actuator. The waist and thigh frames are attached to the user and the actuator works on bending the hip joint. This control is automatized by a hip joint angle sensor and the programmed movement.

First, an interview was conducted to abstract skills. Skill extraction is defined as the understanding of the contents of the skills of an expert and presenting these skills in a form that can be transferred to another person. The skills possessed by an expert already using the walking assist robot in a clinical setting are considered to be the rehabilitation skills. Skill extraction was performed by directly interviewing the expert and recording actual conditions in detail. When actually using the walking assist robot with a patient in a clinical setting, matters of particular importance for decision making are clarified by asking questions repeatedly.

2.2. Results of Skill Extraction from Interview

This section presents the results of the skill extraction through interviewing. The expert was directly asked about procedure for rehabilitating a hemiplegia patient, and the following two facts were determined:

1. Patient classifications correspond to the different rehabilitation methods using the walking assist robot.
2. A patient is classified into one of four patterns based on the patient's manner of walking; this classification is used to select the rehabilitation method.

When expert therapists observe patients walking, they judge these facts and decide what rehabilitation program is applicable to each patient. Because the walking assist robot is not suitable for every patient, it is necessary to reproduce the patient classification; otherwise, the walking assist robot cannot be fully utilized. In addition, since the usage of rehabilitation robot has been found to be different between the first and last halves of the rehabilitation, the contents that should be performed first (first half training) are different from those that should be performed after (last half training).

Patients are divided into four classes based on where the problems exist in walking. Specifically, the experts classified the patient's walking pattern by judging whether the knee joint is extended or flexed and whether the trunk (waist) is thrust forward or left behind. In addition, it was found that the expert investigates when these phenomena occurs during the walking pattern. **Fig. 2** shows the four different classes and where the patients have impaired movement compared to healthy people. A description of each class and the suitable rehabilitation corresponding to each class of patients are described next.

Patients in the first class have impaired movement in the loading response phase when the body weight is supported with both limbs. This class is named "LR-type." The patients in this class first practice the movement from the starting posture where the leg on the affected side is put forward until the final posture where the unaffected side's leg is put forward. In this period, care is taken so that the knee joint is neither overextended nor overbent

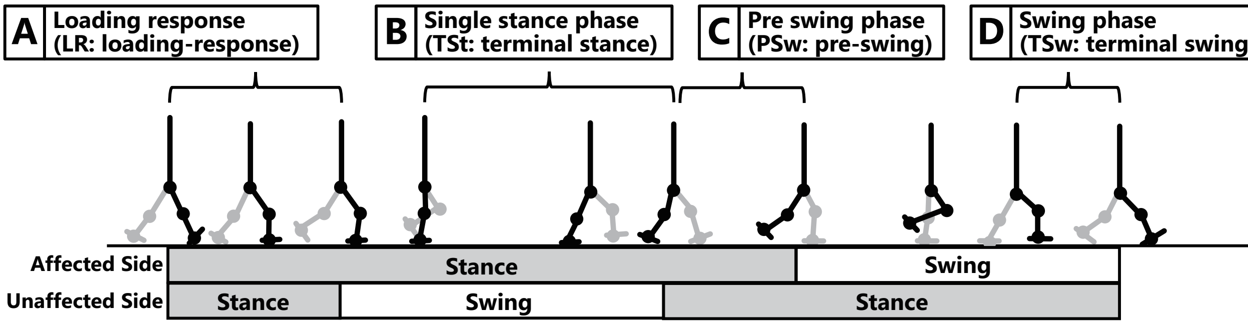


Fig. 2. Four classes of patients. Patients are classified based on when the impaired movement of the affected limb is observed. The first class (LR-type) focuses on the dual stance phase (loading response), the second class (TSt-type) focuses on the single stance phase of the affected limb, the third class (PSw-type) focuses on the preswing phase, and the fourth class (TSw-type) is determined based on the terminal swing phase. The black stick line indicates the affected limb, and the gray line represents the unaffected limb.

from the affected side's heel contact until the double supporting phase. In addition, it is ensured that after the unaffected side's toe lifts off, the trunk is not inclined forward. If this movement is not possible, balance training is provided in the corresponding posture. The extension of the coxa is assisted by the walking assist device at the non-paralysis side step. Next, the patients in this class practice the movement from the time the affected side's toe lifts off until the unaffected side's heel contacts. Here, care is taken so that when the affected side's heel contacts, the contact position is adequately in the forward direction. In addition, it was ensured that after the affected side's heel contacts, the trunk is not inclined forward. The bending of the coxa is assisted by the walking assist robot in the affected side's step.

Patients in the second class have impaired movement in the terminal stance phase when they support their body with their affected limb. This case is named "TSt-type." The period of focus is from the time the affected side's heel contacts until the time the unaffected side's heel contacts. During this period, the extension angle of the affected side's coxa is enlarged. If this event is not possible, the triceps surae muscle activity is encouraged by the back step before the unaffected side. The extension of the coxa because of the unaffected side's step is assisted by the walking assist robot. Next, the patients need to practice from the time when the affected side's heel contacts until when the unaffected side's heel contacts. The body weight is switched to the opposite side as rapidly as possible. The coxa extension is assisted by the walking assist robot in the unaffected side's steps.

Patients in the third class have impaired movement in the preswing phase when they swing the affected limb while standing on the unaffected limb. This class is named "PSw-type." The focus is from the time the unaffected side heel contacts until the time the affected side toe lifts off. The knee of the affected side is encouraged to be relaxed and the patients are told to switch their body weight to the unaffected side. No assist is provided from the walking assist robot, but the affected side is manually moved by the therapists. In the next stage of rehabilitation, the focus is from the time the affected side heel contacts until the next time the affected side heel contacts. Immediately after the unaffected side contact, relaxing of the knees is encouraged. Once the body weight has shifted to the opposite side, the bending of the knees is encouraged. The extension of the coxa is shifted by the paralysis side's step.

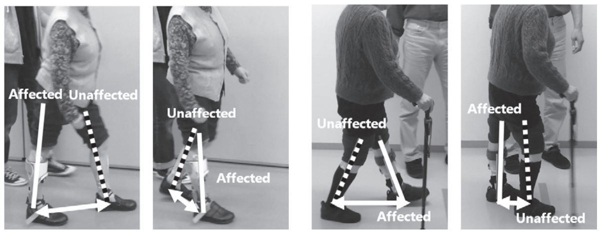
Patients in the fourth class have impaired movement in the last of their affected limb swing phase. This class is named "TSw-type." The focus is from the time the affected side's toe lifts off until the affected side's heel contacts. Immediately before the affected side's heel contacts, the extension of the coxa is encouraged. If these postures are not possible, the coxa on the paralysis side is passively extended. The coxa bending in affected side is assisted by the walking assist robot. After this rehabilitation, the period of focus is from the time when the unaffected side's heel contacts until the next time the unaffected side's heel contacts. The movements up until this point are repeated continuously. The coxa extension is assisted in the affected side's steps.

3. Skill Extraction from Walking Videos

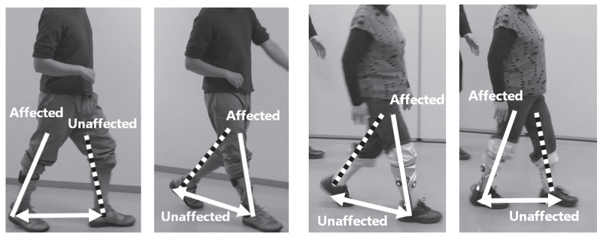
The results of the interviews with the experts in Section 2 show that it is important to classify hemiplegia patients into different types. Eastlack reported limited repeatability of the results of gait analysis observed by physical therapists [15]. Krebs reported that the observed gait kinetics analysis has variability considerably among evaluators [16]. Although a physical therapist analyzes gait pattern of patients with hemiplegia in a clinical environment, the result of the evaluation depends on individual skill and experience due to the lack of clear evaluation criteria. In order to define clear evaluation criteria, Murlroy et al. [17] investigated the gait patterns of patients with hemiplegia at early onset and six months later using cluster analysis. They reported that the criteria for classifying gait patterns can include the knee extension angle in the middle stance phase at early onset, the knee extension angle in the latter stance phase, and the knee flexion angle in the early swing phase. This study focused on the movement of the knee joint. However, the movement of the knee joint is difficult for the non-expert to understand the timing of these types.

Thus, it is necessary to reproduce the pattern classifications of patients to realize the expert's skills; however, the reproducibility of observation-based analysis of walking by different evaluators is known to be low. Experts can classify patients by observing their walking based on their extremely extensive experience; however, it is difficult for a novice physical therapist to reproduce similar classifications.

Therefore, this study aims to develop a method that allows easy reproduction of an expert's classification of hemiplegia patients. Specifically, a method to easily reproduce an expert's patient classification is sought by analyzing a video of different patients walking. This study examined in detail the exact moment that an expert focused on the patient's manner of walking. Data that indicated an expert's classification were used to abstract characteristics that can be applied as classification indices.



(a) LR-type patients (b) TSt-type patients



(c) PSw-type patients (d) TSw-type patients

Fig. 3. Example of walking movement in each class. The white line indicates the affected limb, and the dashed line indicates the unaffected limb.

3.1. Method of Skill Extraction from Videos

The patient classification skill was abstracted based on videos of patients walking. Next, a patient's walking pattern that an expert had separated by type was observed, and items identified as characteristics of a patient's walking pattern were recorded. Based on the results of the interviews, which indicated that the walking event and timing are important, the periods of the supporting phase on the affected and unaffected sides of each patient were measured from the videos. We examined the video based on the gait event defined by a previous study [18]. In particular, the stance phase (in which the foot touches ground) and swing phase (in which the foot is not in contact with the ground) were investigated. The phase when both legs touch the ground is called the double stance phase, and the phase when only one of the legs touches ground is called the single stance phase. Furthermore, hemiplegia patients are known to have asymmetric gait patterns [19, 20]. Among several different measures, step length, which is the length between one leg and the other, is chosen as the metric for classifying patient types.

Focusing on these gait events, we studied videos of 16 hemiplegia patients walking. The expert's classification of these videos were examined. Four patients were of LR-type, two of TSt-type, six of PSw-type, and four of TSw-type. These videos showed about seven walking cycles, and among these walking cycles, we focused on the three-step cycle phase of each patient. Without fixing the perspective, the videos were taken from directions that revealed the motion roughly on the sagittal plane. The frame rate of the videos was 29.97 fps.

3.2. Results of Skill Extraction from Videos

The patient classification methodology based on walking videos is presented in **Fig. 3**, which compares the step length between the affected and unaffected sides of each type of patient. The timing of heel contact for both sides is measured. The solid lines in **Fig. 3** show the affected side legs, while the dashed lines show the unaffected side legs. Furthermore, the white arrows between limbs show the step length.

This study focuses first on step length of each leg of the hemiplegia patients. The LR-type and TSt-type patients shown in **Fig. 3** have remarkably different step length. Moreover, for the LR-type patient, the step length is small when the affected side is put forward, whereas for the TSt-type patient, the step length is small when the unaffected side is put forward. In addition, the step lengths of the PSw-type and TSw-type patients are shown to be almost identical on the affected and unaffected sides. Therefore, analysis from the walking video shows that LR-type and TSt-type could be distinguished by the step length. When the step length of the affected side is shorter than that of the other side, the patients are considered to be LR-type. On the contrary, the patients are classified as TSt-type if the step length of the unaffected side is shorter.

Next, we examined how to distinguish PSw-type and TSw-type using metrics other than step length. To this end, we proposed the walking rate. The walking rate indicates how much time is taken to perform one step. The walking rate was calculated by dividing the number of steps by the overall time consumed in walking. The results of walking rate obtained for each type of patients were 1.28 ± 0.16 steps/s for LR-type, 1.32 ± 0.34 steps/s for TSt-type, 1.24 ± 0.34 steps/s for PSw-type, and 1.84 ± 0.16 steps/s for TSw-type. This index shows that a high value is obtained only for TSw-type patients. These results also show that it is possible to perform a classification appropriately by combining step length and walking rate. **Fig. 4** shows the flow chart for classifying patients.

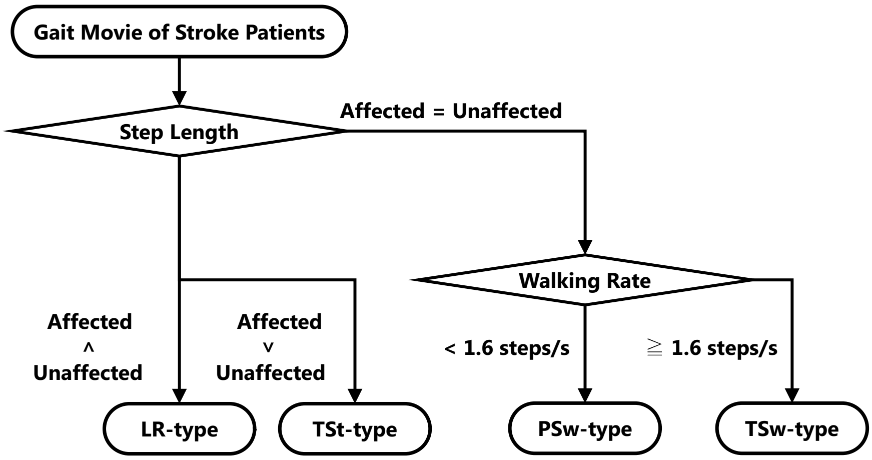


Fig. 4. Flow chart for classifying patients. First, it is determined whether the step lengths of the affected and unaffected sides are equal. Next, the walking rate is examined.

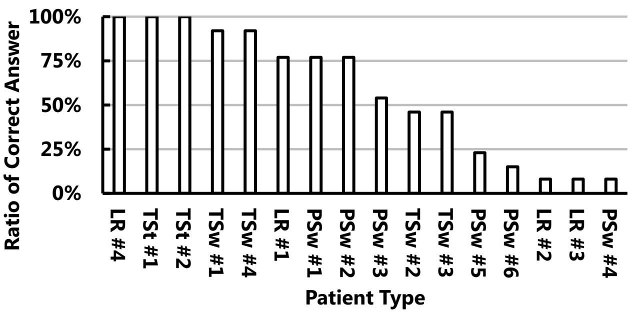


Fig. 5. Histogram to indicate ratio of subjects who could classified each patient into correct type. There were eight patients whose type was identified correctly by 75% or more subjects. However, five patients could be identified correctly only by subjects less than 25%.

3.3. Verification Test of Classification

A verification test was performed to clarify whether extracted skills enable the novice therapist to reproduce the classification using the proposed chart. The subjects were three graduates of a physical therapy course and ten novice students. The subjects observed the aforementioned 16 videos of patients walking and answered the question: "Is the step length larger on the affected or unaffected side, or is it equal on both sides?" The results show that the correct answer rate was 58% for thirteen subjects. **Fig. 5** shows proportion of subjects who could correctly classified the patients. The horizontal axis shows the 16 different patients and the vertical axis shows the ratio of correct answers. From the left (LR#4) to the right patient (PSw#4), the percentage of those who could classify the patient into the correct group decreases. The result shows that half of the patients (eight patients) could be identified correctly by 75% or more subjects. However, there are five patients who were identified correctly by less than 25% of the subjects.

Of these five patients, two were LR-type who actually have larger step length for unaffected limb, but they were misjudged as PSw-type who has equal step length for both limbs. Although the other three patients were PSw-type, two of them were misjudged as LR-type, and one of them was misjudged as TSt-type. Considering the classification chart shown in **Fig. 4**, the subjects misjudged patients between LR-type and PSw-type, and between LR-type and TSt-type. From these findings, it was found that the subjects could not recognize whether the step length was equal or not for certain types of patients. One reason for subjects to misjudge step length of each leg was the viewpoint of the video recording. In the verification test, the subjects did not see the patients themselves, but watched the video of the patients walking. These videos were taken manually by a hand-held camera, and the viewpoint was not fixed. To resolve this situation, it would be better to move the video recorder parallel to the patient. Furthermore, another possible cause of error is that the duration of the movie was too short for the novice subjects to judge the step length. Each movie showed patients who performed 3–5 steps in 2–3 seconds. However, in the real-world rehabilitation environment, patient mobility is usually evaluated by walking 10 m. In this situation, novice participants would be expected to judge better because they could see the patients walking over a longer distance. To further improve this classification methodology, novice therapists are required to either learn a standard for equal step length or find other characteristics to distinguish these patients.

4. Conclusions

This study examined a new rehabilitation technique of using a walking assist robot from the perspective of skill education. In skill education, it is important to clarify the tacit knowledge of the expert and extract essentially important points of that knowledge. By interviewing the expert therapist, it has been found that hemiplegia patients need to be divided into four groups in order to appropriately rehabilitate them using a walking assist robot. Furthermore, we suggested a new patient classification methodology for novice therapists to learn and reproduce the rehabilitation skill as explicit knowledge. We believe that when walking assist robots eventually penetrate society and are used for rehabilitation of hemiplegia patients, it will be possible to use the skills identified in this study to perform patient rehabilitation efficiently.

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Main Works:
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Main Works:
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• "Effects of an ankle-foot orthosis with oil damper on muscle activity in adults after stroke," Gait Posture, Vol.33, pp. 102-107, 2011.

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Main Works:
• H. Yamakawa, H. Hosaka, I. Kobayashi, and K. Itao, "Approximate Analysis for Airflow Damping of Microoscillator: Analysis by Cylinder Model," J. of the Japan Society for Precision Engineering, Vol.72, No.6, pp. 796-803, 2006.
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Membership in Academic Societies:
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Main Works:
• A. Yamashita, T. Arai, J. Ota, and H. Asama, "Motion Planning of Multiple Mobile Robots for Cooperative Manipulation and Transportation," IEEE Trans. on Robotics and Automation, Vol.19, No.2, pp. 223-237, 2003.
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Main Works:
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Main Works:
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Membership in Academic Societies:
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