# Designing for Children 2019
## - Play and Learn

# Development of a robot for emotional support of children during walking rehabilitation

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**Abstract**: Recent advancement in robotics technology has resulted in the increasing involvement of robots in several aspects of children life, including medical and nursing-care services. Within the field of children walking rehabilitation, robots with sophisticated technologies can assist patients' gait training in several physiological ways. However, although pediatric literature pays importance to emotional support during stressing medical procedures, literature review of this study could not find a robot that carries out this function for rehabilitation purposes. This paper describes the development process of an emotional support robot for pediatric walking rehabilitation. A four-steps outline of walking rehabilitation process was defined, and the children emotional states for each step were deduced. Based on these emotional states, the specific robot's emotional roles and motion to accomplish them were defined. Two robot prototypes were built and by on-site and web survey studies the proposed robot design, motion and effectiveness were validated.

***Key words:*** *Walking rehabilitation, Children, Robot, Emotional support*.

## 1. Introduction

The Japanese Ministry of Health, Labour and Welfare has announced a shortage of 377,000 long-term care workers in 2025 (Ministry of Health, Labour and Welfare, 2015). In addition to securing human resources in the nursing care field, the Japanese government also places importance on creating an environment in which high-quality nursing care services can be provided with a limited number of personnel by using robot technology (Ministry of Health, Labour and Welfare, 2019). The purpose of robots providing care is generally to reduce the physical burden of nursing care staff, but there are also robots that provide non-physical care, such as communication robots used for cognitive or emotional purposes (Ministry of Health, Labour and Welfare, 2013).

Within the field of children walking rehabilitation, robots with sophisticated technologies can assist patients' gait training in several ways, mainly by moving or guiding their lower-limbs, supporting body-weight or maintaining appropriate posture. However, although children rehabilitation literature considers emotional support during rehabilitation therapy as an important factor for rehabilitation effectiveness (Yamazaki et al., 2006), literature review of this study could not find a robot that carries out an emotional function for walking rehabilitation.

## 2. Research objective

Through prior literature review and market research, we came up with the idea of a robot for children walking rehabilitation that provides emotional support during therapy and also contributes to strengthen patient's motivation. The purpose of this initial stage of the research is to clarify the emotional roles that the robot must perform during rehabilitation, to design the form and motion of a robot that can fulfill these roles, as well as to validate these elements with a prototype.

## 3. Existing walking rehabilitation robots

For the specific task of walking rehabilitation, this paper found robots that provide active physiological assistance during therapy, such as power suits or "exoskeletons" that increase the strength of legs and hips, fixed or mobile robotic gaits that maintain appropriate posture and balance for walking, and "end-effector robots" that move patient's legs through specific trajectories simulating walking. Additionally, this research found robots that provide instructions and feedback during walking exercises (Fig. 1).

Figure 1. Robots for physiological assistance and guidance during walking rehabilitation <from the left: power suit ([Kid exoskeleton], 2016), mobile gait ([Andago], 2019), "end-effector robot" ([G-EO System], 2021, and walking guiding robot ([TREE], 2017)>

Although there are robots that provide emotional support by delivering calming and engaging effects, this research did not find this type of robots used in the walking rehabilitation field. This is an area of opportunity since rehabilitation therapy patients tend to experience pain and anxiety, and cooperativeness must be enhanced for future sessions. Moreover, research has shown that children are more emotionally sensitive than adults because they are less able to regulate their emotions, so they tend to feel in a stronger way those emotions experienced during rehabilitation [(Ryugo, 2004), (Yamazaki, 2006), (NHK Educational Corporation,2016)].

## 4. Analysis of walking rehabilitation and Definition of robot's roles

### 4.1 General outline of walking rehabilitation

In order to define the robot roles for providing emotional support, it was necessary to clarify specific usage scenarios during rehabilitation therapy, as well as the emotions experienced by children during it. The walking rehabilitation process was studied by carrying out literature review, observation of walking rehabilitation therapies and interviews with physical therapists with experience in pediatric walking rehabilitation. Based on the results, a walking rehabilitation outline that covers preparation to completion of the therapy was summarized in the following four steps (Table 1):

(1)Preparation: A physiotherapist performs stretching and preparation exercises,

(2)Immediately before the start: Transfer to the rehabilitation area or equipment and getting ready,

(3)During rehabilitation: Perform walking rehabilitation, usually with auxiliary equipment, and must complete a defined number of repetitions of a certain exercise or walking distance,

(4)End: Therapy ends when patient has completed the indicated number of exercises, or as indicated by therapist.

### 4.2 Child's emotions and robot roles

In order to define the specific roles of the robot, the emotions of the patient generated in every step of the walking rehabilitation outline were clarified by carrying out interviews with a physiotherapist member of the Japanese Physical Therapy Association, who has experience in pediatric walking rehabilitation. This research speculates positive and negative emotions for every step of the rehabilitation outline, which are summarized in the "Patient's emotional state" in Table 1. Finally, according to the emotions shown by patients on each rehabilitation outline step, proposed specific emotional roles are summarized in "Robot's role towards patient", in Table 1.

Table 1. Steps of walking rehabilitation outline, patient’s emotions and robot’s roles

| | ① Preparation | ② Immediately before start | ③ During rehabilitation | ④ End |
|---|---|---|---|---|
| Step |  | | | |
| Patient’s emotional state (Positive emotion) | How was last time? | I will do my best!<br>I will complete it soon | It doesn't hurt, half more!<br>It doesn't hurt anymore | I worked hard<br>I achieved today's goal |
| Patient’s emotional state (Negative emotion) | Will I fell down?<br>Will I feel pain? | I hope it won't hurt | It hurts, I'm getting tired<br>Must do it for another half | It hurted<br>I don't like it anymore |
| Robot's role towards patient | Remove anxiety<br>Calm down | Let's do it soon<br>I will support you to do your best | I sympathize with your difficulty of walking<br>Affirm that this is okay<br>Support to the goal<br>Show the final point and encourage | You did your best<br>To affirm<br>To Cogratulate |

**5. Design of walking rehabilitation support robot**

**5.1 Concept**

This research envisions an autonomous robot that plays a role as a third party (apart from rehabilitation therapist and family members), and accompanies the walking rehabilitation patient, providing emotional support by its body movements. The target users are children who were able to walk alone, and the ideal flow of interaction between the patient and the walking rehabilitation support robot is as follows: (1)The robot detects the emotions of the patient by automated emotion recognition (AEE) technology. Next, (2)it determines the specific emotional support role that must be performed as well as the motion that can fulfill that role. Then, (3)moves alongside the patient to enhance empathy and sense of unity. The idea is that by repeating steps (1) to (3), the interaction between the robot and the child will be strengthened, and the child's willingness to rehabilitate will improve.

**5.2 Design of robot form**

In order to clarify the effect of its movements, the robot has a simple structure consisting of two sections, a head and a torso without limbs. The external dimensions (width x depth x height) are 240 x 240 x 435 mm. Figure 1 shows the basic structure of the walking rehabilitation support robot.

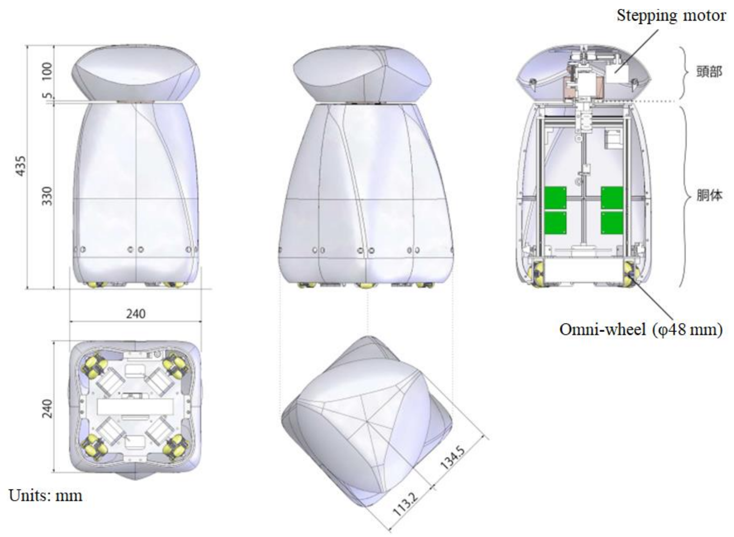


Figure 1. Basic structure of the emotional support robot for walking rehabilitation

The robot being developed in this research has no face, due to the following reasons: First, in the field of balance training and walking rehabilitation, although calling a patient attention from a position in front of him may improve walking stability, precise focusing on a face may distract him/her (Mizuta et al., 2009). Secondly, to avoid changes in patient impression due to facial design preferences. Third one is to take advantage of the omni-wheel capabilities of moving easily in any direction. For example, if a robot that has a face is looking to one direction while moving to the opposite one, it may feel creepy. Hence, by eliminating the face, it can move freely without causing any discomfort.

After repeated examinations using idea sketches and rough models, a design based on the Reuleaux triangle was selected because it is symmetric but curvy at the same time. A right-handed curve was added at an angle of about 75° from the feet to the top for the purpose of emphasizing the rotational movement.

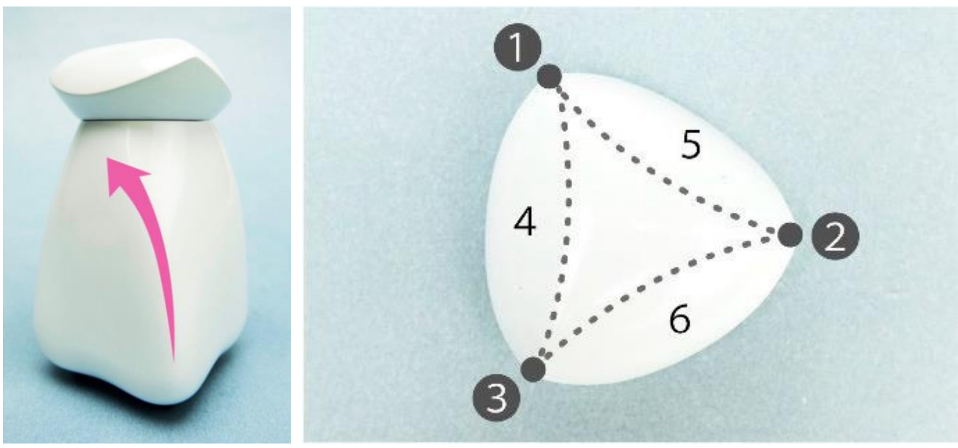


Figure 2. Robot exterior design

### 5.3 Design of robot motion

Considering patients' emotions on each rehabilitation step, discussed in section 4, the following robot actions (movements) for emotional support were defined (Fig. 3).

- At "Preparation" step: In order to decrease anxiety, the robot performs a "slow up and down" reciprocating movement, inspired by the up and down movement of the shoulders when taking a deep breath.
- At "Immediately before start" step: In order to boost positive emotions the robot performs a "quick up and down" reciprocating movement, similar to a energetic gesture of pushing up the fist while cheering.
- At "During rehabilitation" step: In order to express empathy with the difficulty of walking, the robot can accompany the patient by moving at his same walking speed and rhythm, and later on –when the patient gets tired- can locate ahead of him in order to lead and motivate to keep walking. The robot performs a "sliding" movement, in which it goes forward by alternatingly moving ahead the body and then the head.
- At "End" step: In order to affirm the patient's efforts at the end of the therapy and celebrate for achieving the goal with intensity, the robot performs a "reverse rotation" movement, in which body and head rotate in different directions.

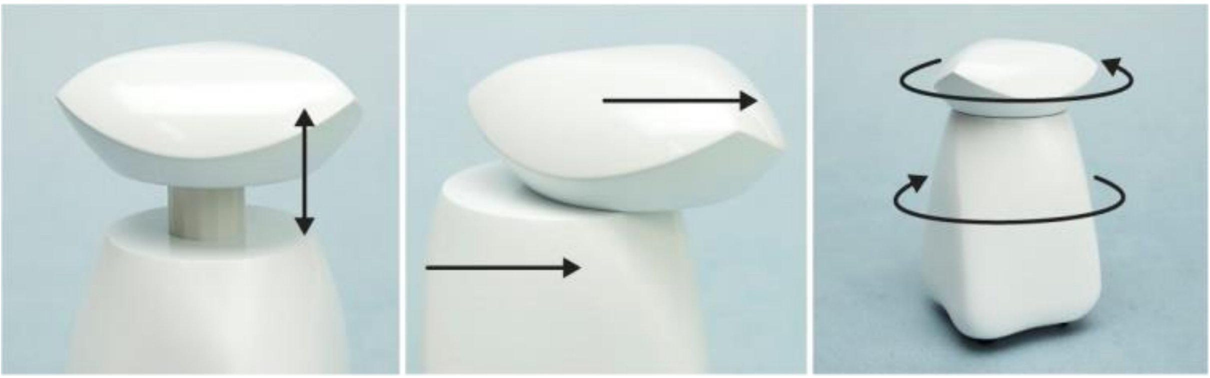

Figure 3. Robot motion (left: up and down, center: sliding, right: reverse rotation)

### 6. Prototyping and validation

In order to validate proposed robot actions and design, two prototypes were built (Fig. 4). The first prototype had medium size (313 mm Width x 313 mm Depth x 600 mm Height) and was used for assessing impression towards robot motion. However, once this prototype was completed it was decided to change its size, so dimensions of the second prototype were reduced (230 mm Width x 230 mm Depth x 435 mm Height). The body shape of the first prototype had to be changed in order to decrease costs for 3D printing. Internal mechanisms and parts of both prototypes are basically the same, having slight differences in size. The prototypes are operated by remote control, since at the present stage of this research the sensing system has not being completed.

Figure 4. Robot prototypes

Since involving children in the validation process of this research became increasingly difficult due to the Covid-19 situation in Japan, prototype evaluations had to be carried out with adult subjects.

### 6.1 Evaluation of impression towards robot motion

The subjects were 20 healthy university students (12 males and 8 females) who were randomly selected at campus. The walking rehabilitation procedure was first explained and then mid-size robot performed the different types of defined motion (Figure 5).

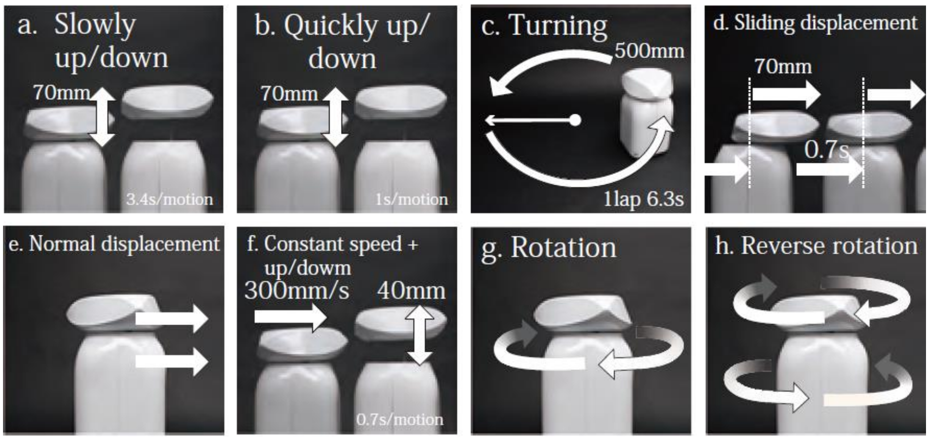

Figure 5. Types of robot motion

The evaluation was performed using the SD method (11 pairs of impression words, 7-point scale). The layout of the experiment and robot trajectories is shown in Figure 6. Table 2 describes each movement of the robot, as well as detailed information of operating speed and moving distance.

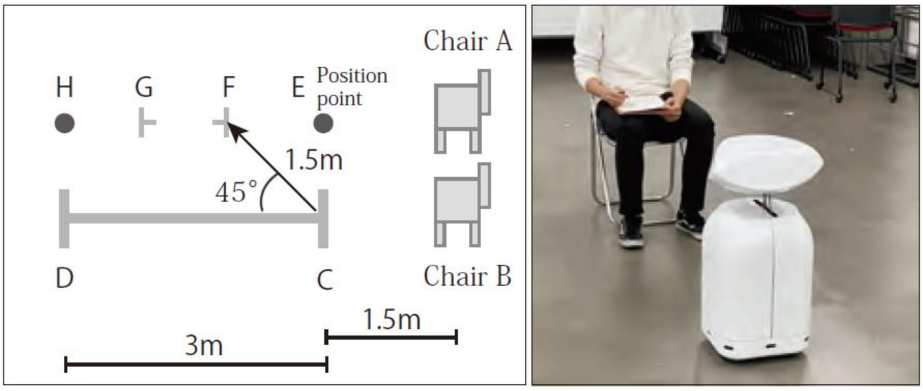

Figure 6. Layout and aspect of the experiment

Table 2. Description of robot motion

| Rehabilitation step | | Robot motion |
|---|---|---|
| Before therapy | | Static state |
| ① Preparation | a | Reciprocating movement that slowly raises and lowers the head (3.4s / reciprocation). |
| ② Immediately before start | b | Reciprocating movement that quickly raises and lowers the head (approx. 1s/reciprocation). |
| | c | Turning motion (6.3 s/lap) with point C in Fig. 3 as the rotation axis. |
| ③ During rehabilitation | d | The head slides and the torso moves forward (moves 70 mm each for the head and torso in 0.7 s). |
| | e | Normal displacement that moves forward while stopping irregularly at the operator's timing. |
| | f | It moves from point E to point H at a constant speed (300 mm / s), stops at point H, and then reciprocates up and down. This vertical reciprocating operation has a height of 40 mm (0.7s / reciprocating). |
| | g | As an operation for repetition, a rotation operation with the center of the robot body as the rotation axis. |
| ④ End | h | Body and head rotates in opposite directions at the same time. (Body: 0.5 rotation/s, Head: 1 rotation/s with respect to the body). |

Using analysis of variance, we compared the impressions of robot movements for each evaluation item and confirmed significant differences in movements. As for the analysis method, one-way analysis of variance (One-way ANOVA) showed a difference in population mean, so a multiple comparison test (Bonferroni) was performed. The main results of the evaluation can be summarized as follows:

- Stationary state, “slow up and down” reciprocating movement and “slow sliding displacement” were associated to an impression of [being calm].
- The movements of “quick up and down” reciprocating movement and “reverse rotation”

movement transmitted an impression of [being energetic and excitement].

- The “up and down” reciprocating movement -regardless of speed- were associated to an impression of [cheering].
- “Sliding displacement” was indicated as transmitting a [cuddling] impression.
- “Reverse rotation” was linked to an impression of [being happy].

From the results of this first evaluation it can be assumed that the movements defined for robot motion can transmit the desired emotion for each of its support roles.

### 6.2 Evaluation of impression towards robot form

An online questionnaire was conducted with the aim of clarifying the impression of the robot exterior design. As stated before, for this evaluation a smaller (by approximately 30%) prototype was produced with the original design (Fig. 4). The questionnaire was responded by a total of 71 persons, with a great majority of university students and some persons from general public (46 men and 25 women). Respondents were asked to evaluate robot images according a set of impression words, which were extracted from past robot sensitivity evaluation experiments found in literature review [(Kanda et al., 2001), (Kanda et al. 2002), (Inoue, 2013), (Mori, 2004), (shibata, 2012)]. The evaluation included comparison of the form of both medium and small size prototypes. The answer method is the SD method (12 pairs of impression words, 7-step scale) and free questions.

As a result of histogram analysis, it became clear that the overall impression of the robot form was evaluated according the following expressions: “good”, “gentle”, “cute”, “I like it”, “sense of stability”, “interesting” and “mechanical”. Comparison of the two prototypes revealed that the smaller robot was higher evaluated as “friendly”, and it became clear that form elements that mainly affect this evaluation are the robot curves lines, rounded form and smaller size. On the question “Do you think the small prototype has a face?” 43 people (60.6%) answered positively. For such cases, we asked to select the robot area that looks like a face, and most of these respondents selected the area in the head with protrusions. Among them, few respondents had a negative impression of this protruding (“mechanical”, “unfriendly”, and “scary”), but there at the same time few persons said that protruding elements makes the head to look “cute”, “as an animal”. As a conclusion of this evaluation it can be said that the majority of respondents had a positive overall impression of the robot form, with an image associated to positive adjectives that match the intended robot emotional roles. However, regarding the robot face, the fact that more than half or respondents perceived the robot as having a face requires further analysis. Regarding this matter, it may be inferred that, some respondents found scary to perceive a face in the robot while not having explicit face attributes.

### 6.3 Evaluation of overall impression by healthcare professionals

The purpose of this evaluation is to clarify the impression regarding the robot form and the effectiveness of the robot movement for each role. A total of 10 medical professionals (6 nurses, 2 medical universities professors, 1 nursing teacher and 1 physiotherapist) participated in this evaluation, carried out by a web questionnaire. As for the evaluation method, the concept of the robot and the defined outline of walking rehabilitation were explained, together with the design intention of the robot form and motion. Short videos of every motion of the robot were included for evaluation (Fig. 7). These videos were shown in an order according to the rehabilitation outline steps discussed in section 4.

Figure 7. Screen capture of a video of the prototype motion used in the evaluation study

The analysis method was SD and free questions. For the impression of the robot form, 5 pairs of impression words were evaluated on a 7-points scale, and for the effectiveness of each movement, evaluation was done with a 7-points scale. Although 10 respondents are not an adequate statistical sample, the study results are summarized as follows:

- In evaluation of the overall impression of the robot form, impressions tended to "good", "I like it" and "mechanical". Although there were favorable opinions such as "its unique shape can help to call kid's attention" and "I think it may be easier to get along with the robot without a face than having one", a contrasting opinion such as "it might be a little scary for kids" was also obtained.
- On the evaluation of the 8 proposed robot motion, 7 movements were satisfactorily evaluated, with more than half of respondents considering each movement to be effective for its intended emotional role. Only "sliding displacement" was considered not effective for the role of expressing empathy with the difficulty of walking.
- The usefulness of the robot in its present state (operated by remote control, without automated functions) was favorably evaluated by more than half of respondents. Similar results were obtained regarding the willing to use a robot incorporating automated functions.

## 7. Conclusions

This study aimed the realization of an emotional support robot for children walking rehabilitation by first clarifying the emotional roles that the robot must perform during rehabilitation, designing the form and motion of the robot that can fulfill these roles, and finally performing validation of these elements by using prototypes.

Although a final goal of this research is to develop a robot with a high level of automation, presently the robot prototype is operated by remote control. At this state, the overall impressions of the robot design, motion and effectiveness have been favorably evaluated. These results may allow concluding that using the proposed robot for emotional support for pediatric walking rehabilitation could be effective.

It is clear that the weakest point of this research is that children have not been formally involved in the evaluation studies, due mainly to difficulties related to Covid-19 pandemic. Due to this situation the evaluation studies of the robot form and effectiveness were performed online. However, although the number of medical professionals who participated in the evaluation was low, their opinions tended to be as favorable as the one obtained by other respondents. Overall, obtained results have been encouraging, and not favorable opinions also shed light on issues that can be improved. These results also suggest a potential to use the robot for adults walking rehabilitation.

From a design perspective, a valuable contribution of this research has been working toward a direction of a faceless robot. Despite the strong tendency of setting face features in robot design, this research has been explored a different direction with satisfactory results. Nevertheless, a more comprehensive validation requires involving children and performing a quantitative evaluation with more statistical power, as well as on-site qualitative observation.

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