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Algorithm for Selecting Appropriate Transfer Support Equipment and a Robot Based on User Physical Ability

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Abstract—**In this present paper, we propose an algorithm for selecting appropriate transfer support equipment and robot based on the physical ability of the user. In addition, we describe the relationship between physical human features and the burden during standing when using a standing support robot. Although a number of care support devices have been developed, assistive robots are not yet popular because users do not know which devices are appropriate for their needs or physical abilities. In this study, we focus on a transfer support device and propose an algorithm for selecting transfer support equipment and a robot that suits the user's physical ability. We investigated the relationship between standing support equipment including a robot and the physical burden during standing, which is a basic transfer motion. Experimentally, we analyzed and calculated the knee and ankle joint moments and discussed the relationship between standing support equipment and knee and ankle joint moments during standing; we also investigated and the relationship between physical human features and the knee joint moment during standing. Our results identified standing support equipment that was appropriate to the user's physical ability. We found that it was effective to provide an up/down seat to persons having low residual ability; a standing support robot is appropriate for people having less residual ability in the knees, and a railing is suitable for people having low residual ability in the ankles.**

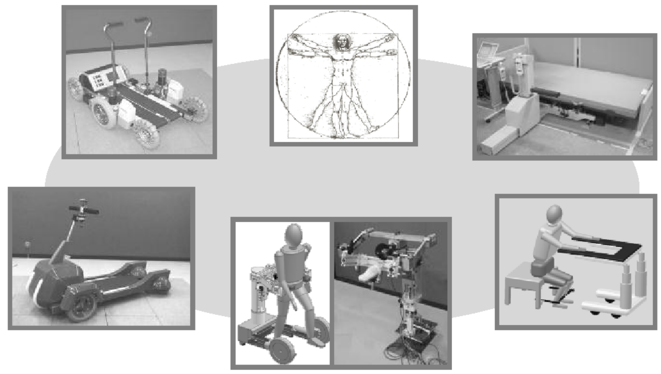

Fig. 1. Human support robots.

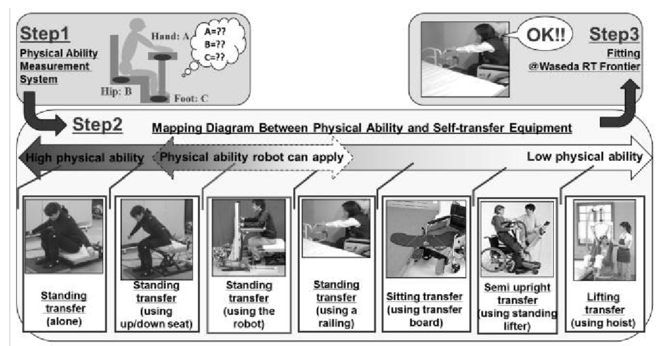

Fig. 2. Algorithm for selecting appropriate transfer support equipment based on the physical ability of the user.

I. Introduction

CARE support robots and their development have gained a great deal of attention in Japan because of the limited number of caregivers and the costs of employing caregivers for elderly patients. Thus, it is important that such individuals as the elderly and disabled individuals who require nursing care have the opportunity to live an independent life through the use of self-support equipment and their own residual physical ability.

Although a number of researchers have proposed care and self-support robots, as shown in Fig. 1, these robots have not yet become popular. For example, Hitachi Co., Ltd. developed a walking support robot [1][2], and Paramount Bed Co., Ltd. designed a support machine that works together with a high-low moving electric bed to help individuals get out of bed [3][4]. In addition, Chugo et al. developed a robotic walker with standing assistance [5]. However, most of these studies considered only their own assistive robot without making comparisons with other devices. Although it is essential to ascertain which assistive robot is most suitable for a particular physical ability, to date, no selection algorithm has been developed for such assistive robots.

On the other hand, Medical doctors (MDs) and physical therapists (PTs) arbitrarily select assistive equipment or devices for individuals who require nursing care. Thus, the user may be unable to live an independent life using the selected assistive equipment because the equipment is not appropriate to their physical ability.

Moreover, a number of caretakers suffer from back pain because they have to support patients manually during lifting transfers, such as when a patient is moved from a bed to a wheelchair. Therefore, there is a significant cost associated with injury compensation to caretakers [6]. Yasuda [7] recommended a "No Lifting Policy" in Japan, and this guideline was formally adopted by the Australia Nursing

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Federation in March 1998. Currently, this guideline prohibits caretakers from performing lifting transfers using only human power. However, many caretakers are familiar with only a few support devices and cannot easily judge which transfer equipment is the most suitable for the needs and physical abilities of their patients.

In the research and development of self-support robots and devices, the following problems are encountered:

1) Not Established: Quantification of physical ability and an algorithm for selecting self-support equipment have not been established. Thus, self-support equipment may not be suitable for the physical ability of the user and could reduce the quality of life (QOL).

2) No Equipment: Since there is here a lack of transfer support equipment or independent walking support devices appropriate for the physical ability and needs of the user, the patient must rely on the support of a caregiver. This in turn prevents the patient from making use of their own physical abilities, thereby diminishing their independence.

3) No Place: There is no place for the user to try out and select self-support equipment.

Based on these considerations, we herein focus on transfer support for the prevention of disuse syndrome.

--Quantification of the physical ability of the user and establishing an algorithm for selecting transfer support equipment (Fig. 2).

--Development of a new transfer support robot for individuals for whom there is no suitable equipment based on their physical ability according to the above algorithm.

--Establishing the basis for testing human support robots and making an experiment, and general population are able to do a fitting the transfer support equipment according to the above algorithm.

II. Approach of the Present Study

The present study was conducted in four phases.

(1) We determine the parameters by which to express the physical ability of the user (residual ability).

(2) Based on experimental results, we simulate the physical tasks involved in using common transfer equipment and the standing support robot we are developing.

(3) We develop a machine that can measure the parameters determined during phase 1.

(4) We compare the physical ability measured by the machine developed in phase 3 with the simulation results obtained in phase 2 and construct an algorithm for selecting appropriate transfer equipment and a robot based on the physical ability of the user.

The experimental device for measuring residual ability noted in phase 3 has been constructed. The accuracy of this device in measuring the burdens on the legs and postural sway was reported at the Welfare, Wellbeing, Life Support 2010 conference [8].

To construct the algorithm for selecting appropriate transfer support equipment based on the physical ability of the user in phase 4, a preliminary experiment was carried out. The aim of this experiment was to examine the physical burden during standing when using standing support equipment and the standing support robot. The results confirmed relationship between the residual abilities of the ankle and knee joints and the appropriate standing support equipment and robot. In addition, we proposed a relationship between the physical features of the user and the physical burden during standing, which is a basic transfer motion.

Fig. 3 Standing support robot

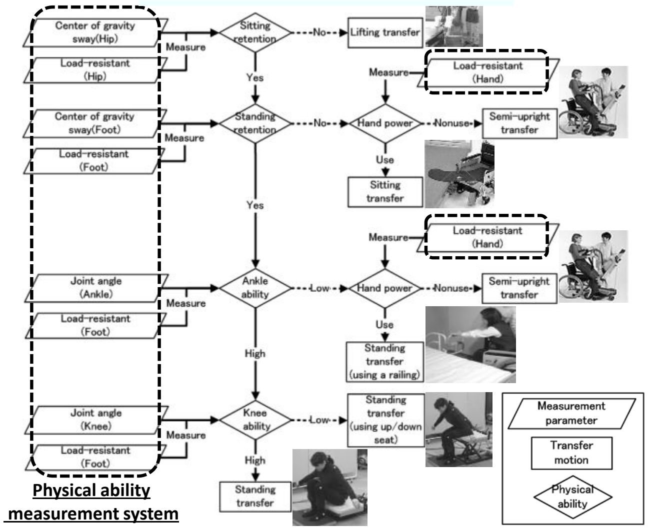

Fig. 4. Transfer classification and parameters for expressing physical ability.

III. Classification of Transfer

The association of Japanese Rehabilitation Engineering published a report entitled, "Transfer Technique -Thinking and Method" [9]. In this report and another study [10], transfer motion was classified into the following three groups:

1) Lifting Transfer: Caretakers and individuals who require nursing care use a hoist to lift patients. There are two types of hoist. The first is designed for individuals who cannot maintain a sitting or standing position. Such devices include the Care Lift KQ-771 (Paramount Bed. Co., Ltd.) and the Partner Electric Run Type BMA201 (Meidenkohsan Co., Ltd.). The second type of hoist is designed for individuals who are capable of sitting but cannot maintain a standing position. Such devices include the Molift Quick Raiser 2 (Molift Ltd.).

2) Sitting Transfer: In this type of transfer, caretakers and individuals who require nursing care use a sliding board or a sheet to slide the hip of the user onto the equipment to assist transfer. Such devices include the Easy Motion MEMV (Molten Co.).

3) Standing Transfer: There are several types of standing transfer; the first type does not involve the use of supplementary equipment; the second type uses an up/down seat to lift the user's hip; the third type uses a railing, such as an assistance bar, attached to a bed; and the fourth type uses a standing support robot, such as the one that we are developing (Fig.3).

Based on the classification of these transfer types and also on PT and MD recommendations and preliminary experiments, we developed a transfer classification system and set of parameters[11] by which to express physical ability (Fig. 4).

IV. Relationship between Residual Ability and Appropriate Transfer Support Equipment

The objective of the present study was to construct an algorithm for selecting transfer support equipment appropriate to residual ability as shown in Fig.2. The method for identifying how the transfer support equipment classified in Section III affects the corresponding residual abilities remains to be developed. Because standing motion is a basic transfer motion, the present study was a preliminary experiment to determine how standing support equipment and the robot affect the burden during standing. We examined whether a standing support equipment and the robot actually affected residual ability; a particular focus was on the ankle and knee joints, which bear a greater burden when a person stands. The equipment and robots were selected to match the residual ability. Thus, we considered that it would be possible to construct an algorithm for selecting appropriate transfer support equipment and a robot based on the physical ability of the user from the results of this experiment in addition to other experiments using other types of transfer support equipment.

V. Preliminary Experiment to Examine Appropriate Transfer Support Equipment and Robot Based on User Physical Ability

A. Objective

The objective of this experiment was to determine whether the selected transfer support equipment and robot matched the residual ability of the user. We considered joint moment as an indicator of physical burden because muscular tension is reflected by joint moment; based on joint moment, we can determine the intent of a user with respect to the movement of their body and can therefore quantitatively evaluate the appropriate muscular group [12]. A number of other evaluation indicators physical burden can be expressed, including joint moment and muscle force and power. However, since these indicators depend on joint moment, we decided to focus on joint moment in the present study. In the experiment described below, the subjects were young people who were able to perform standing transfer. From the results of this experiment, we could determine what level of physical ability is necessary for a user to perform standing transfer.

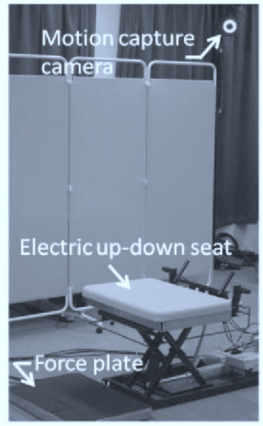

Fig. 5. Experimental setup.

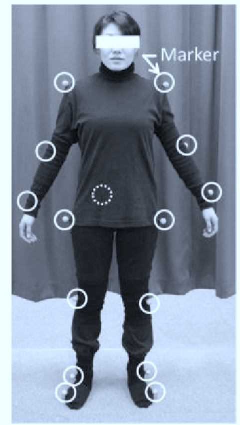

Fig. 6. Marker placement.

Fig. 7. Experiment conditions: (a) Seat low, (b) Seat high, (c) Seat low with railing, (d)Standing support robot with seat high, Measurements are in millimeters

TABLE I
Physical Features of Subjects

Subject	Gender	Age	Height cm	Weight kg
m1	Male	30	173.0	71.0
m2	Male	23	176.0	78.0
m3	Male	24	162.0	48.0

B. Methodology

Toward the above objective, we measured the joint burden during standing. The experimental set-up is shown in Fig. 5. An electric up/down seat (Riku-raku KPZC-101, Aisin Seiki Co., Ltd.) was placed on force plates (OR-6-7-200, AMTI). The subjects were asked to sit on the chair in a position that would allow them to stand up and sit down three times during each test. In addition, we asked them to move slowly and to ignore the influence of inertial force due to acceleration. All the subjects wore black clothing to which markers were attached (Fig. 6) for use with the motion capture system (VICON®, Ver.524). Marker setting positions were determined according to the VICON manual [13][14] . This experiment was performed with four healthy subjects, as described in Table I. The experimental procedure is as follows.

The experimental conditions were as follows; (a) Seat low, (b) Seat high, (c) Seat low with railing and (d) Standing support robot with seat high(Fig. 7). We measured the floor reaction force using the force plate and the marker trajectories as obtained using VICON. The standing support robot that we are developing guides the user's arms to stand similar to PT [14].

Based on the recorded data, we calculated the ankle, knee, and hip joint moments using Diff Gait (Clinical Walk Analysis Seminar) [15][16]. We modeled the human body as being composed of seven segments, as shown in Fig. 8, and the intersegment forces and moments are shown in Fig. 9, where I_i is the moment of inertia, $\ddot{\beta}_i$ is the angle of the joint, m_i is the mass of link i, L_i is the length of link i, l_i is the position of the center of gravity (COG) of link i (where i = 1, 2, and 3 denotes the hip, the knee, and the ankle, respectively), F is the anterior-posterior floor reaction force, N is the vertical floor reaction force, f is the anterior-posterior intersegment force and n is the vertical intersegment force in Fig. 9.

The right ankle joint moment (M_{AR}), right knee joint moment (M_{KR}), and right hip moment (M_{HR}) are calculated using the following equations [16]:

$$
\begin{aligned}
M_{AR} &= I_{3R}\ddot{\beta}_{3R} - F_R(y_{AR} - y_{TR}) \\
&+ m_{3R}\ddot{x}_{AR}(l_{3R}/L_{3R})(y_{AR} - y_{TR}) - N_R(X_{COP} - x_{AR}) \\
&+ m_{3R}(\ddot{y}_{AR} + g)(l_{3R}/L_{3R})(x_{TR} - x_{AR}),
\end{aligned} \quad (1)
$$

$$
\begin{aligned}
M_{KR} &= I_{2R}\ddot{\beta}_{2R} \\
&- \{f_{AR} - m_{2R}\ddot{x}_{KR}(l_{2R}/L_{2R})\}(y_{KR} - y_{AR}) \\
&- \{n_{AR} - m_{2R}(\ddot{y}_{KR} + g)(l_{2R}/L_{2R})(x_{AR} - x_{KR}) \\
&+ M_{AR},
\end{aligned} \quad (2)
$$

and

$$
\begin{aligned}
M_{HR} &= I_{1R}\ddot{\beta}_{1R} \\
&- \{f_{KR} - m_{1R}\ddot{x}_{HR}(l_{1R}/L_{1R})\}(y_{HR} - y_{KR}) \\
&- \{n_{KR} - m_{1R}(\ddot{y}_{HR} + g)(l_{1R}/L_{1R})(x_{KR} - x_{HR}) \\
&+ M_{KR}.
\end{aligned} \quad (3)
$$

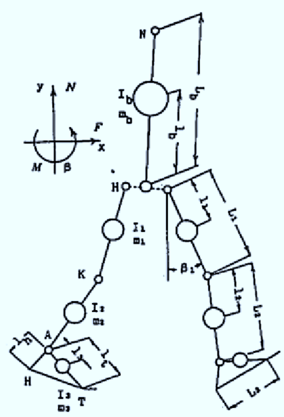

Fig. 8 Link model.

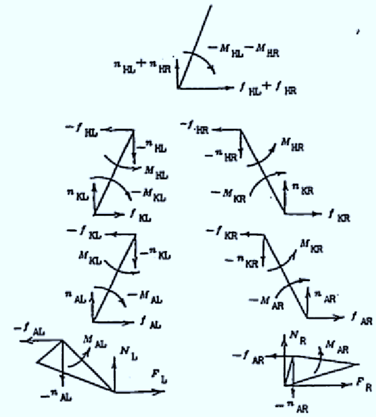

Fig. 9 Intersegment forces and moments.

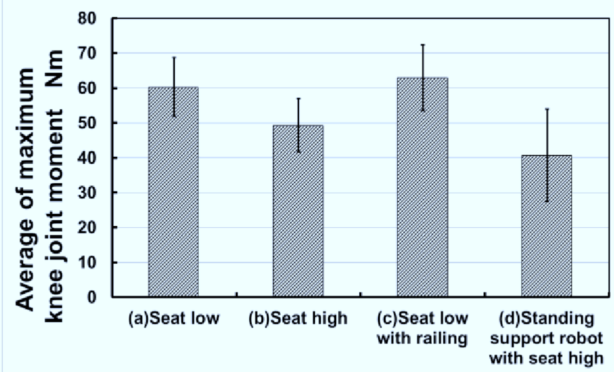

Fig. 10 Relationship between experimental condition and average of maximum knee joint moment

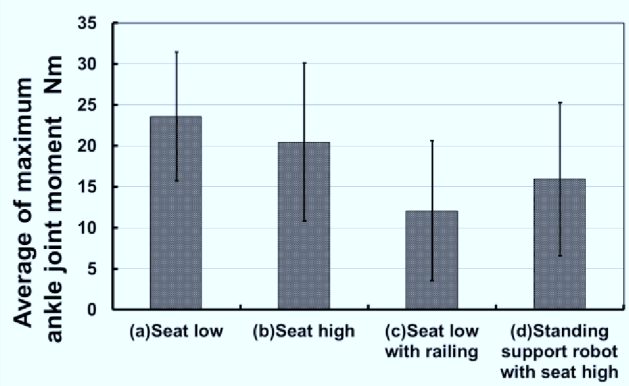

Fig. 11 Relationship between experimental condition and average of maximum ankle joint moment

Results

In the present study, we focused on knee and ankle joint moment because these moments bear the greatest burden in individuals who require help in standing transfer. Fig. 10 shows the maximum values of the moments acting on the knee joints under the experimental conditions and Fig. 11 these values for the ankle joints. The subjects in this experiment were healthy young people who were able to stand up under all experimental conditions; thus, the maximum moments acting on the various joints indicated the physical strength necessary to stand up under all conditions. In addition, the subjects moved slowly, and so we consider that there was no great difference between these young healthy people and elderly people.

We defined the relationships between the subjects' weight and height and the average of three maximum knee joint moments, as shown in Figs. 12 and 13, respectively. These figures provide the approximation curves and expressions for each experimental condition.

C. Discussion

1) Fig. 10 shows that for all the subjects, the average of maximum moment on the knee joint was low in the case of high seat (b); with the standing support robot (d), it was lower than in (b). This suggests that the residual ability in the knee joint can be used effectively. In the same manner, chairs with up/down seats can be used for people who have low residual ability in their knee joints, and the standing support robot can be used for people who have less residual ability than that required for the up/down seat.
2) Fig. 11 shows that for all the subjects, the average of maximum moment on the ankle joint was low in the case of the low seat with the railing (c). This suggests that the residual ability in the ankle joint can be used effectively. In the same manner, the railing can be used for people who have low residual ability in their ankle joints.
3) The experimental results indicate the benefit of appropriate standing assist equipment and a robot based on the user's physical ability at the affected joints. If an algorithm for selecting transfer support equipment and a robot appropriate to residual ability were constructed, users would be able to make effective use of their joints, thereby putting less load on the parts of their bodies that had less residual ability. In addition, robots can change their movement by adjusting to the user's situation and physical ability. It is necessary to have a standing support robot that is able to accommodate wide range of users physical abilities.
4) In this experiment, subjects stood up using an up/down seat and a standing support robot. Variations were observed in the residual ability required to do these motions. Considering the parameters expressing physical ability and the transfer classifications proposed in Fig. 4 in Section III, it appears to be necessary to incorporate the use of a standing support robot. Figure 14 incorporates this additional aid.
5) In Fig. 12, the fits of the estimated coefficients (R^2 values) were as follows: (a) Seat low, 0.996; (b) Seat high, 0.661; (c) Seat low with railing, 1.00; and (d) Standing support robot with seat high, 0.492. In Fig. 13, the fits of the estimated coefficients (R^2 values) were as follows: (a) Seat low, 0.998; (b) Seat high, 0.642; (c) Seat low with railing, 0.999; and (d) Standing support robot with seat high, 0.472.

   From the above estimates, we propose that under certain conditions, there is a proportional relationship between weight and height and joint moment according to the physical ability of the user.
6) We plan to repeat this experiment with a large number of subjects, a wider range of physical features, and more standing support robot movements. In this way, we aim to gather more conclusive evidence and determine whether there is any relationship between physical features and other joint moments.

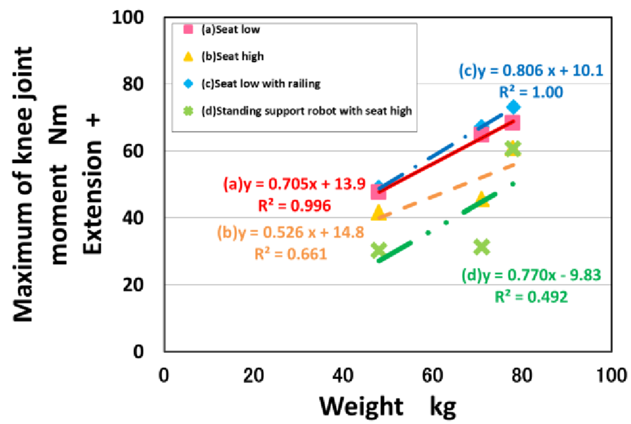

Fig. 12 Relationship between weight and average of maximum ankle joint moment

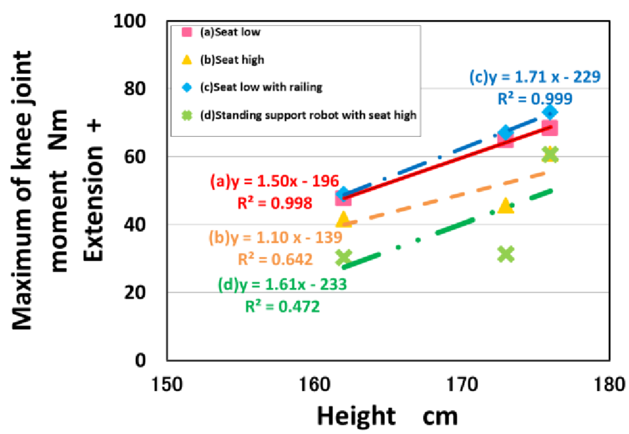

Fig. 13 Relationship between height and average of maximum knee joint moment

VI. Conclusion

We have proposed the quantification of physical ability and an algorithm for selecting transfer support equipment and a robot that suit for the user's physical ability. In this study, we developed a transfer classification system and parameters by which to express physical ability; we investigated the relationship between standing support equipment and a standing support robot and the physical burden during standing transfer, which is a basic motion of transfer. In our experiment, we analyzed and calculated the knee and ankle joint moments. In addition, we discussed the relationship between the standing support equipment and robot and the knee and ankle joint moment during standing. The experimental results indicated a relationship between the burden on the ankle and knee joints during standing and the standing assist device; the results suggested the benefit of using a transfer support that is device appropriate to the residual ability of the user. For users with low residual ability in the knees, chairs with up/down seats and other aids are effective. Users with less residual ability in the knees can use the standing support robot we are currently developing, whereas railings should be provided for users with low residual ability in the ankles.

In addition, we investigated the relationship between human physical parameters and the knee joint moment during standing. The results indicate that under some conditions, there is a proportional relationship between the weight and height of the subject and the maximum knee moment when the subject stands up from a chair. We intend to repeat this experiment using a greater number of subjects with more varied physical features, such as gender, height, and weight. Future experiments should examine additional relationships between necessary levels of residual ability and other types of transfer support equipment. We anticipate the development of an algorithm for selecting transfer support equipment that suits the user's physical ability.

To this end, we renewal opened the Waseda RT(Robot Technology) Frontier (Fig. 15), which is the research center of the present authors for the Global COE Program Global Robot Academia in 2012 in Shinjuku, Japan. Here, ordinary can try out support robots and we can perform our robot experiments and support fitting of the robots to individual users. We intend to conduct experiments with ordinary people as subjects instead of individuals in the laboratory. In the future, we also aim to start up a robot fitting business at RT Frontier based on an algorithm for selecting transfer support equipment. This will include robots that suit the user's physical ability, and these we intend to establish in future studies.

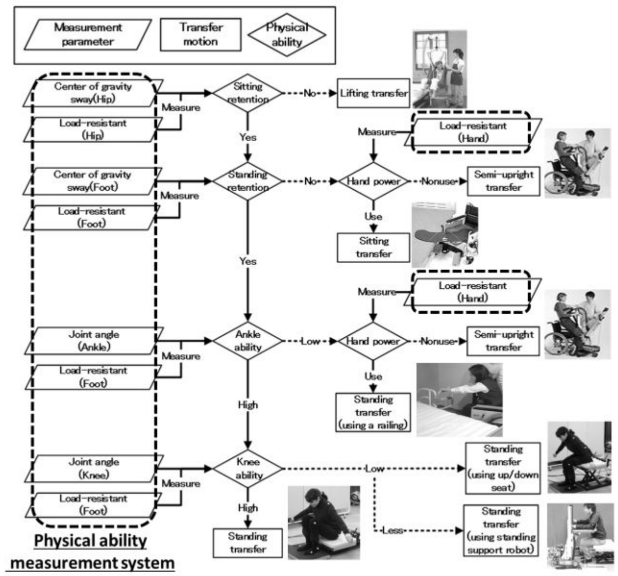

Fig. 14. New transfer classification and parameters for expressing physical ability.

Fig. 15. RT Frontier

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