33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Algorithm for Selecting Appropriate Transfer Support Equipment Based on the Physical Ability of the User

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Abstract—**In the present paper, we propose an algorithm for selecting appropriate transfer support equipment based on the physical ability of the user. In addition, we describe the relationship between features of the human body and the physical burdens during standing. Although several care support devices have been developed, assistive robots are not yet popular because users do not know which devices are suitable for their needs or appropriate for their physical abilities. In the present study, we focus on a transfer support device and propose an algorithm for selecting transfer support equipment that will be suitable to the physical ability of the user. We investigated the relationship between standing support equipment and physical burdens during standing, which is one of transfer motions. In an experiment, we calculated and analyzed the knee and ankle joint moments and discussed the relationship between standing support equipment and the knee and ankle joint moments during standing. The results indicated a difference in the relation of standing support equipments appropriate to the user's physical ability. It was found effective to provide a railing to persons having low residual ability in the ankle joints and an up/down seat to persons having low residual ability in the knee joints.**

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 individuals such as elderly or 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 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.

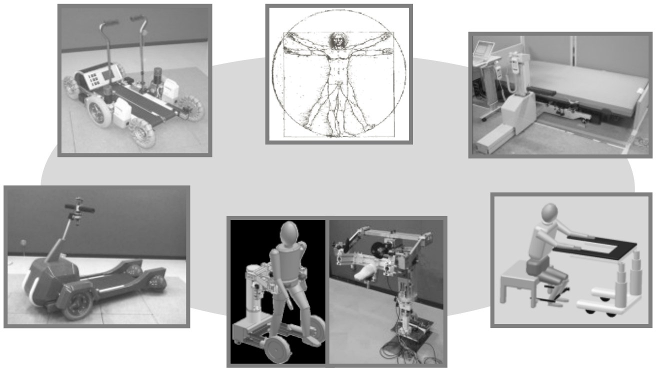

Fig. 1. Human support robots.

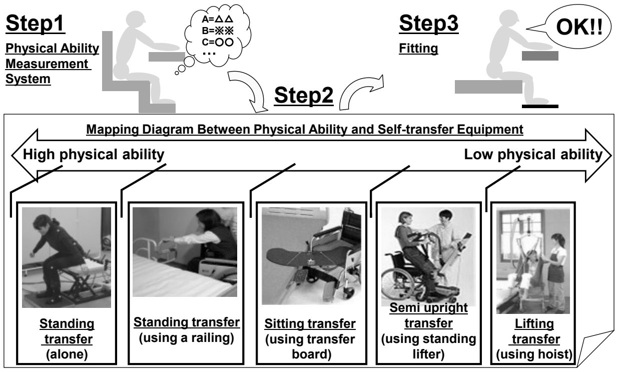

Fig. 2. Algorithm for selecting appropriate transfer support equipment based on the physical ability of the user.

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 still not be able 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 must support patients manually during lifting transfers, such as when a patient is moved from a bed to a wheelchair. Therefore, there is significant cost associated with injury compensation to caretakers [6]. Yasuda [7] recommended a "No Lifting Policy" in Japan, which was also

Manuscript received April 15, 2011. The present study was supported in part by the Global Centers of Excellence Program "Global Robot Academia" through the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) and in part by a Grant-in-Aid for Scientific Research (22700583) from MEXT.

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978-1-4244-4122-8/11/$26.00 ©2011 IEEE

formally adopted by the Australia Nursing Federation (ANF) Victoria branch office 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 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, the self-support equipment may not be suitable for the physical ability of the user and may reduce the quality of life (QOL).

2) No Equipment: Since there is no transfer support equipment or independent walking support devices that are suited to the physical ability and needs of the user, the patient must rely on the support of the 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 where the user can 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 the establishment of a transfer support equipment selection algorithm (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 algorithm established herein.

--Establishment of a basis for testing human support robots and making an experiment, and where general population can do a fitting the transfer support equipment according to the algorithm established herein.

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 the experimental results, we simulate the physical tasks involved in using common transfer equipment.

(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 based on the physical ability of the user.

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

In the present paper, we propose parameters by which to express the physical ability of an equipment user. In addition, in order 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 in order to examine the physical burdens during standing with some standing support equipments. The results confirmed relationships between ankle and knee joint residual abilities and appropriate standing support equipments.

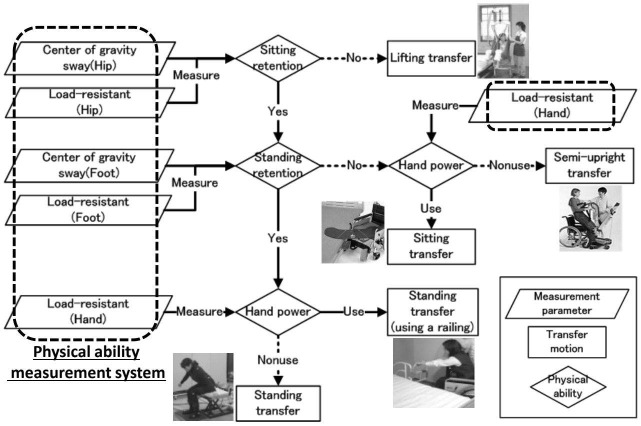

Fig. 3. Transfer classification and parameters for expressing physical ability.

III. PARAMETERS TO EXPRESS PHYSICAL ABILITY

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 has been 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 hoists. 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 two types of standing transfer. The first type uses a railing, such as an assistance bar attached to a bed, and the second type does not involve the use of supplementary equipment.

Based on the classification of these transfer types and based on PT and MD recommendations, we developed a transfer classification system and parameters by which to express physical ability (Fig. 3).

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 Fig.2. The method by which to identify how the transfer support equipment classified in Section III affects the corresponding residual abilities remains to be developed. The present study is a preliminary experiment to determine how a standing support equipment affects the burdens during standing, because standing motion is one of the fundamental transfer motions. Whether a standing support equipment actually affects residual ability was examined, with particular focus to the ankle and knee joints, which bear higher burden when a person stands up. Equipments are selected to match the residual ability. Thus, we consider that it will be possible to construct an algorithm for selecting appropriate transfer support equipment based on the physical ability of the user from the results of this experiment and other experiments using other transfer support equipments.

V. PRELIMINARY EXPERIMENT TO EXAMINE THE APPROPRIATE TRANSFER SUPPORT EQUIPMENT BASED ON THE PHYSICAL ABILITY OF THE USER

A. Objective

The objective of this experiment was to determine whether transfer support equipments selected to match the residual ability of the user. We consider joint moment as an indicator of physical burden because muscular tension is reflected by joint moment, and based on joint moment, we can determine the intent of a user with respect to the movement of his or her body and can therefore evaluate the appropriate muscular group quantitatively [11]. There are a number of other evaluation indicators by which to express physical burden, including joint moment and muscle force and power. However, since these indicators depend on joint moment, in the present study we focus on joint moment. In the experiment described below, the subjects are young people who can perform standing transfer. Based on the results of the experiment, we can discuss what level of physical ability of a user is sufficient to perform standing transfer.

B. Methodology

In order to verify the objective, we measured the joint burden during standing. The experimental set-up is shown in Fig. 4. An electric up/down seat (Riku-raku KPZC-101, Aisin Seiki Co., Ltd.) was placed on force plates (OR-6-7-200, AMTI). Subjects were asked to sit with their hips 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 to move slowly to ignore the influence of inertial force due to acceleration of quickly motion. All subjects wore black clothing to which markers were attached (Fig. 5) for use with the motion capture system (VICON®, Ver.524). Marker setting positions were determined according to the VICON

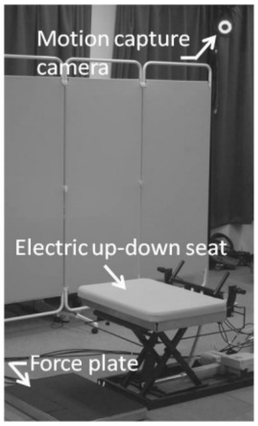

Fig. 4. Experimental setup.

Fig. 5. Marker placement.

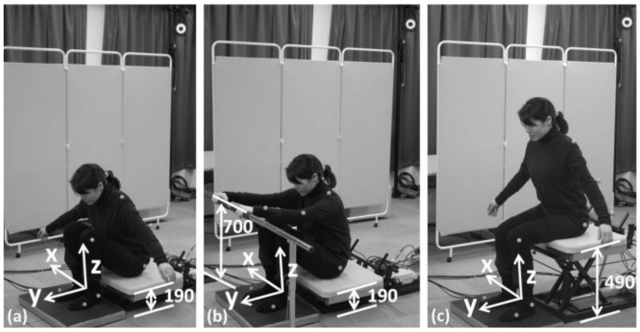

Fig. 6. Experiment condition: (a) Seat low, (b) Seat low with railing, (c) Seat high. Measurements are in millimeters.

TABLE I
BODY FEATURES OF SUBJECTS

Subject	Gender	Age	Height cm	Weight kg
m1	Male	21	164.5	49.6
m2	Male	23	175.0	84.5
m3	Male	25	173.9	62.0
m4	Male	23	166.0	62.0

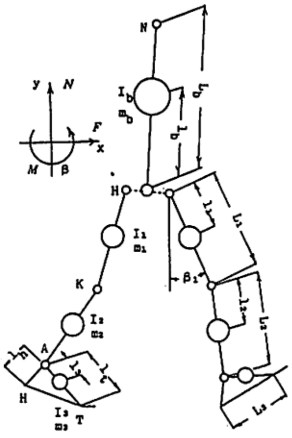

Fig. 7 Link model.

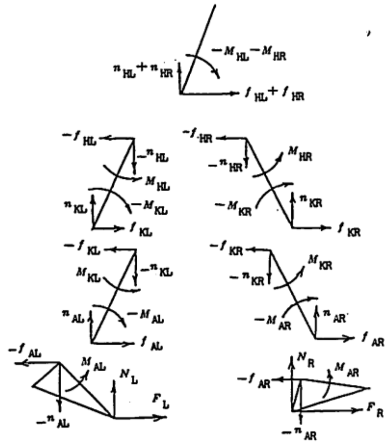

Fig. 8 Intersegment forces and moments.

manual [12][13] . This experiment was performed with four healthy subjects, as described in Table I. The experimental procedure is as follows.

The experimental conditions are (a) Seat low, (b) Seat low with railing, and (c) Seat high (Fig. 6). We measure the floor reaction force using the force plate and the marker trajectories as obtained using VICON.

Based on the recorded data, we calculate the ankle, knee, and hip joint moments using Diff Gait (Clinical Walk Analysis Seminar) [13][14]. We model the human body as being composed of seven segments, as shown in Fig. 7, and the intersegment forces and moments are shown in Fig. 8, 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 denote 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. 8.

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 [14]:

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

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

and

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

C. Results

In the present study, we focus on the knee and ankle joint moment because these moments bear the greatest burden in individuals who require help in standing transfer. As an example, the knee and ankle joint moment of Subject m3 during standing from the Seat low position is shown in Fig. 9, the Seat low position with railing is shown in Fig.10 and Seat high position is shown in Fig.11. Figure 12 shows the maximum values of the moments acting on the knee and ankle joints under the experimental conditions. The subjects in this experiment were healthy young people who were able to stand up under all experimental conditions, and so the maximum moments acting on the various joints were

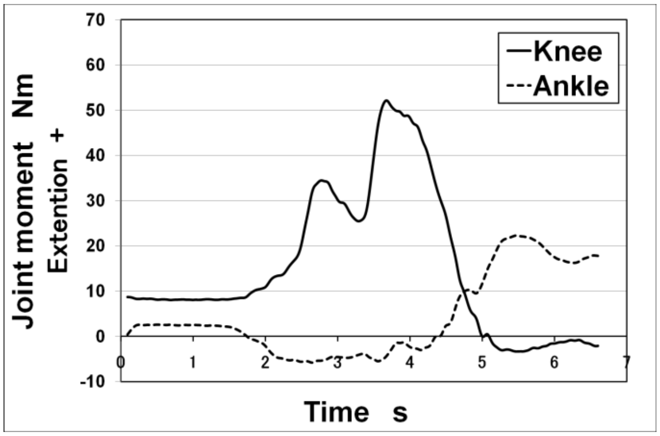

Fig. 9 Knee and ankle joint moment (Subject m3, Seat low).

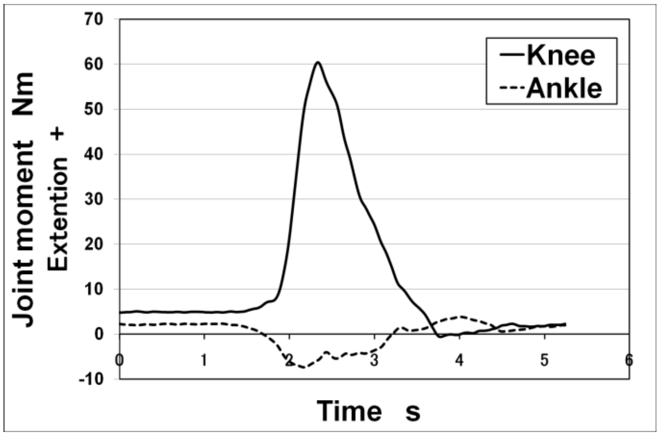

Fig. 10. Knee and ankle joint moment (Subject m3, Seat low with railing).

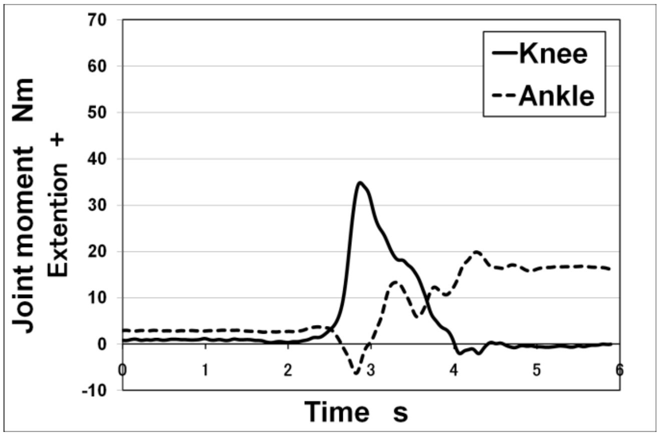

Fig. 11. Knee and ankle joint moment (Subject m3, Seat high).

informative of the physical strength necessary to stand up under all of the conditions. In addition, subjects moved slowly, so we consider that there is so not difference between young healthy people and elderly people.

D. Discussion

1) Figures 9 through 11 reveal that among the experimental conditions the maximum moment about the knee joint occurs during standing up. Similarly, with the exception of the case in which the subject used the railing to stand up, the moment about the ankle was maximum just before the subject reached the standing position. Figure 10 shows that using a railing resulted in an overall reduction in the moment on the ankle joint. This was due to some of the subject's weight being distributed to the rail during standing. Thus, the railing is an effective tool for reducing the load on the ankles.
2) Figure 12 shows that, for all of the subjects, the maximum moment on the ankle joint was low in the case of the low seat with the railing (b) and in the case of the high seat (c). 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 the knee joints. Raising the seat reduces the load on the knee joint and allows the individual to effectively use the residual ability in their ankle joints.

   The experimental results indicate a benefit from an appropriate standing assist equipment based on the user's physical ability at the affected joints. If an algorithm for the selection of transfer support equipment appropriate to residual ability is constructed, users will be able to make effective use of their joints, putting less load on the parts of their bodies that have less residual ability.

   In this experiment, subjects stood up unassisted from a seat that had been set to (a) a low position and (c) a high position. 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. 3 in Section III, it appears to be necessary to incorporate the use of a chair with an up/down seat for the appropriate measured values for load-bearing on the foot and knee joint angle. Figure 13 incorporates this additional aid.

VI. CONCLUSION

We herein proposed the quantification of physical ability and an algorithm for selecting transfer support equipment that is suitable for the physical ability of the user. In the present study, we developed a transfer classification system and parameters by which to express physical ability and investigated the relationship between standing support equipment and physical burdens during standing transfer, which is a type of transfer motion. In the experiment, we calculated and analyzed the knee and ankle joint moments. In addition, we discussed the relationship between standing

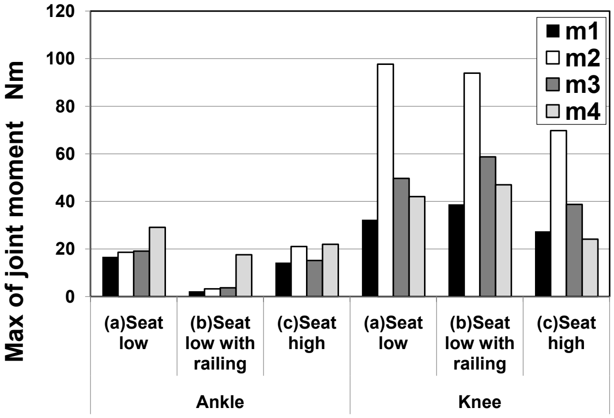

Fig. 12. Maximum of ankle and knee joint moment.

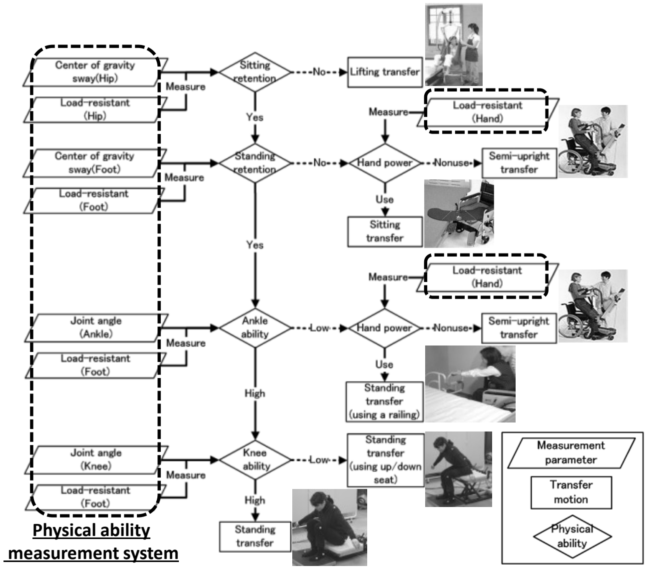

Fig. 13. Transfer classification and parameters for expressing physical ability.

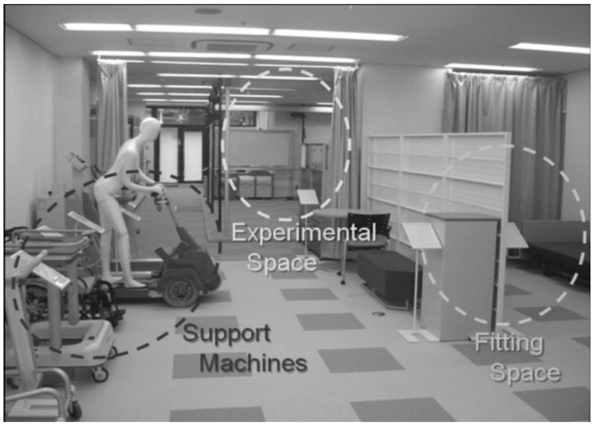

Fig. 14. Communication Square for Man and Robot (COSMAR).

support equipment 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 and suggested a benefit from using a transfer support device appropriate to the residual ability of the user. It is effective to provide a railing to users having low residual ability in the ankles and to employ chairs with up/down seats, or other aids, for users with low residual ability in the knees. Future experiments should examine additional relationships between necessary levels of residual ability and other transfer support equipments. We anticipate the development of an algorithm for selecting transfer support equipment that is suitable for the physical ability of the user.

To this end, we opened the Communication Square for Man and Robot (COSMAR) (Fig. 14) at RT Frontier, which is the research center of the present authors for the Global COE Program Global Robot Academia in 2009 in Shinjuku, Japan, in order to enable users to try out support robots, perform experiments, and support fitting of the robots to individual users. We intend to conduct an experiment using ordinary people as subjects instead of individuals in the laboratory. In the future, we intend to start up a "robot fitting business" at COSMAR (Fig. 15) based on the algorithm for selecting transfer support equipment that is suitable for the physical ability of the user which will be established in future studies.

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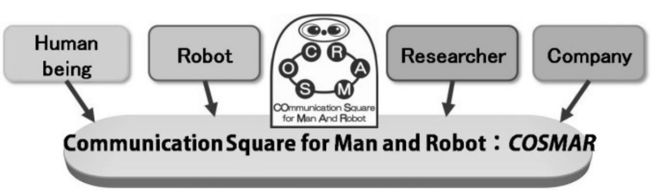

Fig. 15. Future of COSMAR.