Kinematic analysis of standing up by patients with rheumatoid arthritis supported by a service dog

（慢性関節リウマチ症例の介助犬使用による立ち上がり動作分析）

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Kinematic analysis of sit to stand by persons with rheumatoid arthritis supported by a service dog

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Abstract

Purpose: The objective of this study was to quantify the kinesiological effect of the assistance provided by service dogs on transferring from sit to stand in persons with rheumatoid arthritis (RA).

Methods: Twenty-four participants performed a total of eight experimental transfers of sit to stand, including unassisted transfers, transfers with a cane, and transfers with assistance from a service dog. I analyzed movements at the lower extremity joints using a three-dimensional kinematics system and two force plates.

Results: At the hip joints, the range of motion changes and energy expenditure with a cane and with the service dog were smaller than that of the unassisted transfers. Transfers with a service dog resulted in less joint movement and less energy used in movements at the knee and ankle joints; participants also scored themselves as requiring less effort on a self-rating scale than in the other conditions.

Conclusion: A service dog provides benefits in assisting with transfers from sit to stand by persons with RA. Future studies should consider training the service dogs to assume correct positions and use appropriate timing to support their partners during these transfers.

Key words: Force plate, Human, Motion, QOL, Service dogs, 3D analysis

1. Introduction

Rheumatoid arthritis (RA) is a life-long autoimmune disease, which results in the inflammation of the joints and their surrounding tissues [1). This painful condition results in joint destruction, limitations in range of motion and strength of the affected joints. Further, muscle atrophy results from the chronic disease process. Therefore, persons with RA can have difficulty completing daily tasks independently, especially activities that include transfers and mobility.

Persons with disabilities (PWD) often need special equipment or human assistance to help them carry out social activities and to promote their quality of life (QOL). In addition to the use of equipment, the involvement of assistance animals to help PWD has been recently emphasized [2). Service dogs, which are a type of assistance animal, mainly provide assistance to counter physical impairments [3). However, to the best of my knowledge, no systematic study has been conducted to investigate the effectiveness of service dogs in assisting the physical activities of their partners.

A service dog assists its partner in various ways. One major task with which they assist their partners with impairments of the lower, or even upper, extremities to come from sit to stand by acting as a brace from which its partner can push off or to pull the partner forward while the partner holds the dog's harness. I investigated the effectiveness of service dogs to help people come to stand from a seated position. Coming to stand from a seated position is a basic requirement to move and start various walking activities. Thus, independent movements in coming to stand from a chair have been investigated using kinesiological [4-6] and pathophysiological [7-10] methods.

Arthropathy of the wrist and knee joints and significantly reduced functional performance are symptoms that commonly result from rheumatoid arthritis [11, 12]. For those persons with impairments of the upper and lower extremities, a service dog could be a potential assistant as well as a non-pharmacological therapeutic intervention [13]. Since a service dog provides physical force to assist its partner's movements. Further, precise movements, which may be needed to control assistive equipment,, are not required to handle the dog. I thought the kinematic effect of a service dog on tranfers in patients with rheumatoid arthritis could be clearly shown. Therefore, in the present study, I analyzed the movement of coming to stand from a seated position in people impairments of the lower and upper extremities due to rheumatoid arthritis, under the experimental conditions of being assisted with and without a service dog. I planned to determine the load on joints and the energy expenditure required by their extremities using a force plate and a 3-dimensional motion analyzer as study participants transferred from a seated position to a standing position.

The objective of the present study was to quantify the kinesiological effects of assistance provided by service dogs on the movements of a person with RA, assuming that the physical benefits provided by the service dog included traction of the participant, with appropriate timing learned by the dog.

2. Methods

2.1. Study Participants

The study participants were volunteers at an outpatient clinic of the Orthopedic Department, Nagoya University Hospital, Nagoya, Japan. Written informed consent was obtained from all participants prior to start of the study, which was approved in advance by the Ethical Committee of the School of Health Sciences, Nagoya University.

Twenty-four participants with rheumatoid arthritis were enrolled. The mean age of the study participants was 54.6 ± 9.7 (SD) years (range: 30-74 years), with their mean weights and heights being 49.1 ± 8.4 kg (range: 35-65) and 154.8 ± 5.7 cm (range: 142-164), respectively. The mean Barthel Index score was 88.8 (range: 80-95). Severity and functional classification of the participants' disabilities were expressed using the stages of the American College of Rheumatology classification (ACR) [14, 15], summarized in Table 1.

Two trained service dogs participated in the study. The sizes of the dogs are shown in Table 2. Both dogs were registered with the Japanese Support Dog Association, and had been well trained in basic behaviors for supporting clients during transfers.

2.2. Experimental design

2.2.1. Transfers from Sit to Stand

Participants seated on a height-adjustable chair were instructed to stand up from a seated position under the following eight conditions (including three conditions without a service dog and five with a service dog), (Fig. 1).

1) Standing up without any support, including no support using participants' own hands (unassisted).

2) Standing up using a general self-help device (cane).

3) Standing up by the participants supporting themselves with the upper extremities on the chair (self-supporting).

4) DSPB (Dog, Side facing, Pushing, Back): A service dog in a position with its side facing the front of the participants. The participants

stand up by pushing the back of the service dog with both hands. Thus, the participants use the dog as a wall.

5) DSHB (Dog, Side facing, Holding, Back): A service dog in a position with its side facing the front of the participants. The participants' stand up by holding and pulling the back of the service dog with both hands. The participants use the dog as a balustrade.

6) DFHN (Dog, Facing, Holding, Neck): A service dog in a position facing the participants. The participants stand up by holding the neck of the service dog with both hands. The participants use the dog's neck as a thick pole.

7) DFCN (Dog, Facing, Contact, Neck): A service dog in a position facing the participants from as near a position as possible. The participants stand up by holding the neck of the service dog with both hands. The participants use the dog's neck as a pole contacting them.

8) DFMN (Dog, Facing, Move, Neck): A service dog in a position facing a participant. The dog first pulls the participant forward, with the participant supporting his hands on the dog's shoulders with both

hands, thus the participants comes to stand. Here, the dog moves to pull the participants at a pace that enables them to stand up.

Each participant was asked to stand up at his or her own pace with his or her feet in natural positions. The height of the chair was adjusted to match the height of the fibula head of each participant. When the participant could not come to stand from chairs of this height, the height was lowered to a height at which they could stand up.

Participants practiced each trial several times and performed each of the eight movements of coming to stand three times. Therefore, twenty-four trials were performed for by each participant, with short rests periods between each trial. When a subject did not stand up successfully, the trial was repeated. The order of the trials was pseudo-randomized, though the selection of a dog for each subject was randomized.

2.3. Self-rating Score for Coming to Stand Movements

Participants first reported the intensity of the effort they required each time they came to stand from a seated position, on a Self-Report, Perceived Exertion (SRPE) scale, a modified version of the rating of perceived exertion (RPE) [16]. The SRPE scale is a visual analogue estimation scale with values from 0 to 5: a score of 0 = unable to come to stand with assistance (extremely difficult); score of 1 = major assistance required to come to stand (very difficult); scale 2 = minor assistance required to come to stand (difficult); scale 3 = able to come to stand without assistance (moderate); scale 4 = able to come to stand with minor effort (easy); scale 5 = able to come to stand without effort (very easy).

2.4. Data collection

The coming to stand movements were analyzed using a three-dimensional (3D) kinematics system (Vicon Motion System-6) and two force plates (OR6-6, Advanced Mechanical Technology, Inc., MA), simultaneously. The 3D-kinematic analysis system comprised six infrared cameras (MX-F40, Vicon) with pictures taken at a sampling rate of 60 Hz. The cameras, which were placed around the participants, captured 3D positions of reflective markers (diameter, 20 mm). Ten reflective markers were attached to key points of each participant's body: the acromion process, greater trochanter, lateral tibial condyle, lateral malleolus, and fifth metatarsal head on both sides, so as to determine axes and angles of segments of the body (Figs. 1 and 2). From the 3D kinematics system, the positions of the markers were recorded and reconstructed in 3D using a computer system. Two force plates (60 x 90 cm) were aligned adjacent to each other and in front of the participants (Fig. 1). The 3D forces from participants' feet were recorded with the force plates. The sampling rate from the force plates was 60 Hz. The chair, assistive device (cane), and service dog did not affect the force plates. All data were time-synchronized using laboratory-developed kinematics and kinetics software (Vicon Workstation Version 4.6, Vicon, England). The software enabled the calculation of joint centers, the velocity of the whole-body center of mass (CoM) kinematics, 3D joint angles with angle velocity, resultant forces, and moment at the ankle, knee, and hip joints throughout the movement. Due to the limited number of sampling markers, I focused my analysis on movements of the lower extremities as in the previous study of coming to stand [17].

The self-rating score on the SRPE scale was asked in each trial when the participant finished coming to stand. Researchers showed the visual analogue scale for the SRPE, and the participant indicated the level of exertion required by the trial on the scale. Self-rating scores and data obtained by kinematic analyses from three successive trials of coming to stand were collected and averaged for each condition for each subject.

2.5. Data Analyses

For the kinematic analyses, a seven-segment model, (e.g., the feet, shanks, thighs, and trunk with pelvis) was employed [18]. From the 3D kinematic recording data for each joint in the lower extremities, maximal angle change, maximal moment, and energy used at both sides of the joint were calculated. In accordance with the standardized method of Kerrigan et al. [19], each value was standardized by height and weight. To eliminate the effects of asymmetry between the legs, the movements of the lower extremities were provided as mean values of the two sides, as described previously [20]. In addition to the values from the 3D kinematics system and the force plates, the temporal pattern of the moment at each joint was recorded.

For self-rating scores and data obtained by kinematic analysis, two-way (each value and standing-up conditions) analyses of variance (ANOVA) with repeated measures were used to evaluate the effect of coming to stand on the movement. When the effect of the condition was significant, Fisher's protected least significant difference (PLSD) test for multiple comparisons was applied to compare the effect among the conditions. I considered *p* values of less than 0.05 as significant. I focused on significant differences between conditions with and without a service dog.

3. Results

All participants eventually performed the standing-up movement in all conditions, although some participants needed to repeat the procedure three times in order to enable two successful recordings. Since a significant effect of conditions was found, a multi-comparison analysis was applied for each value analyzed.

3.1. Self-rating score

The SRPE score differed significantly among the conditions in which the coming to stand movement was performed ($F=2.4$, $p < 0.05$). The multiple comparison tests in SRPE score revealed that all conditions with a service dog, namely, DSPB, DSHB, DFHN, DFCN, and DFMN, were more effective with higher SRPE points than the unassisted and cane conditions (Fig. 3).

3.2. Maximum angle change

The maximal angle change at the hip joint in the unassisted condition was significantly smaller than in the conditions with a service dog in the DSPB, DSHB, and DFHN positions ($p < 0.05$, Fig. 4). No significant differences in maximum angle change at the knee joint were found among the conditions. The angle change of the planto-flexion movement of the ankle joint in the unassisted condition was significantly smaller than that in the DFCN condition, and that in the cane condition was smaller than those in the DFHN and DFMN conditions ($p < 0.05$). The maximum dorsi-flexion movement of the ankle joint in the cane condition was smaller than that in the DFCN condition ($p < 0.05$).

3.3. Maximal joint moment

The maximal extension moment at the hip joint in the unassisted condition was significantly larger than in the conditions of DSHB and DFCN ($p < 0.05$, Fig. 5). The moments at the knee joint in DSHB and DFCN were also smaller than that in the self-supporting condition ($p < 0.05$). The planto-flexion moment in the cane condition was significantly smaller than those in the DSHB and DFMN conditions (Fig. 5, $p < 0.05$).

3.4. Energy used at joint

The amount of energy used at the hip joint in the cane condition during the movement was smaller than those in the DFCN, unassisted, and self-supporting conditions (Fig. 6, $p < 0.05$). The amount in the cane condition was larger than in the DSHB condition at the knee joints, and was smaller than that in the unassisted condition in the whole lower extremities (Fig. 6, $p < 0.05$).

3.5. Joint moment pattern

Figure 7 shows the average waveforms of the moment at hip and ankle joints during the process of standing up for all participants. The result for the unassisted condition shows one peak of the waveform of the moment at the hip and ankle joints. For the processes of standing up self-assisted and with a cane, the results showed essentially similar waveforms of the moment with one peak. However, all conditions with a service dog showed two peaks of the moment at the hip. Two peaks were also found in the waveforms of the moment at the ankle joint in the DSPB and DSHB conditions.

4. Discussion

In the present study, I found some advantages in the use of a service dog for standing up. In general, the cane, self-supporting, DSHB, and DFCN conditions required less effort of the lower extremities; standing up with the cane required less flexion and energy. However, the cane condition required more moment with more energy at the knee joint than the self-assisted condition, which showed minimal moment and energy values. The total energy used in the legs was also less in the cane condition than in the unassisted condition. These results suggest that the cane could reduce the effort made by the lower extremities, although the effort tended to be shifted to the knees. When the participants could support themselves or use the cane without difficulty, the self-supported or cane condition might be most appropriate to decrease their effort in coming to stand.

Three phases from the onset (sitting position) to the end of the movement (upright position) were reported [21, 22]; (i.e., the flexion-momentum phase, the momentum-transfer phase, and the extension phase). The flexion-momentum phase begins with the first notable movement of the head and ends with the subject leaving the seat. The momentum-transfer phase begins with the subject leaving the seat and ends at the time that the maximum vertical ground reaction force is exerted. The extension phase begins with the maximum vertical ground reaction force being exerted and ends when the marker on the shoulders reaches its maximum vertical displacement when an erect standing posture is attained. Next, I discussed the effects of a service dog on the coming to stand movement of the participant considering those phases.

The DFCN condition involved coming to stand with a service dog facing the participant. By holding and pulling the shoulders of the service dog with both hands, the participants generated a force to pull themselves forward. In this condition, the service dog helped to generate a forward force, and the participants could lean their bodies forward with less hip flexion. Thus, the flexion angle and extension moment of the hip joint were small in the DFCN condition. For the DFCN condition, the vertical forces at each joint and foot were not different from those recorded for the unassisted coming to stand, since participants did not push down on the service dog. The DFCN condition showed less dorsi-flexion of the ankle compared with the cane condition. Since participants had to place each foot to the sides of the service dog in the DFCN condition, the relative position of the feet was more distant from the participant's body than that in the other conditions. I consider that the initial posture caused a slight extension moment of the ankle and slight dorsi-flexion of the joint during the process of standing up. The position of the service dog was considered a factor that affected the position and maximum angular movement of participants' ankles.

The DSHB condition was the condition in which a service dog was positioned with its side facing the participants, and participants stood up by holding and pulling the back of the service dog with both hands; thus, the service dog 'braced' to bear the weight of the participants. Similar to the DFCN condition, pulling the dog generated a forward force in the DSHB condition. However, the distance between the dog and the subject was greater in the DSHB condition than that in the DFCN condition, in which the dog stood between the lower extremities of the participants. Thus, in the DSHB condition, the participants had to lean their trunks forward by flexing the hip joints more than in the DFCN condition. Owing to the distance between the dog and the participants, the participants generated a forward force by reaching to pull the dog, and the movement phase was changed immediately to the extension phase from the initial leaning of the trunk. Because the force was transmitted near the hips owing to the short duration of the leaning phase, the extension moment at the hips was less than in the unassisted condition. The participants pushed down on the dog in the DSHB condition during the extension phase, and the vertical force on the lower extremities was less than in the DFCN and unassisted conditions. As a result, the moment at the knee joint was also reduced. I determined that the major reason for the difference in movement between the DFCN and DSHB conditions was that the dog was in a position that made it easier to push down on the dog compared with the DFCN condition.

Leaning of the trunk by flexion of the hip joint has been shown to indicate the participants' effort to move their CoM forward [20, 23]. The present results showed that the DSHB condition does not always necessitate the minimal effort in movement of the CoM, although the leaning of the trunk gives stability to the trunk.

Most persons with rheumatoid arthritis have limitations in the range of joints motion due to muscle weakness. Joint problems often start at the ankles. Therefore, for persons with limitations of the ankle joints, the DSHB and DFMN conditions, which resulted in relatively high degrees of movement at the ankle joints, were not as suitable as the cane and the DFCN conditions.

When persons with RA have limitations of the knee joints, the DSHB and DFCN conditions are recommended, since these coming to stand conditions require less knee moment during standing up than the other conditions. Similarly, for persons with hip limitations, the DSHB and DFCN conditions might have some benefits, since these conditions result in less moment at the hips compared to the other conditions. However, when persons have limited range of joint movement, the DSPB, DSHB, and DFCN conditions are not suitable, but the cane condition, which requires less angle changes at the hip for coming to stand, may be selected. Regarding the movement of the hip joint, an appropriate coming to stand condition can be selected according to the degree of impairment.

Sibella et al. [24] and Yu et al. [6] reported that temporal patterns of joint moment in the lower extremities exhibited one peak during standard (unassisted) coming to stand in healthy participants, as seen in the present study (Fig. 7). When participants stood with the help of a service dog, the temporal pattern of the moment of the hip and ankle joints exhibited two peaks (Fig. 7). I determined that the peaks were generated by the flexion-momentum and extension-momentum phases, which were usually combined by the momentum-transfer phases in unassisted standing up by healthy participants. The two phases might not combine smoothly in persons with RA due to muscle weakness or joint impairments [8, 25]. The participants in the present study were all new to using a service dog for assistance, although exercises for coming to stand with a dog were practiced prior to the recording. The movement patterns were not identical to those of persons who were well trained to manage a service dog.

The DFMN condition was the coming to stand movement with a service dog that pulled the participants forward to help them lean forward. In this condition, the dog helped to move the CoM of the participants. In this condition, the plantar-flexion moment was significantly greater than that of the condition with the cane. However, the timing of pulling the subject by the dog definitely affected the movement. A service dog with an experienced owner can learn the required timing of the movement to match that of its partner; however, in the present study, since the dog did not know the appropriate timing to move with each participant, the dog started to move when instructed by the trainer. Thus, the effectiveness of the service dog might not have been fully exhibited in the DFMN condition. Therefore, it was thought that the participants performed the coming to stand movement more easily in the other conditions (DSHB and DFCN) with a service dog than in the DFMN condition.

In the self-supporting coming to stand condition, muscle strength or impairments of the upper extremities was an important factor. In RA patients, problems in the upper extremities, especially arthritis in the hands, are common. Although the biomechanical model for healthy participants indicated that the moment or torque at the knee and hip joints decreased when using upper extremities for support [4, 25], rarely did the participants have difficulty supporting themselves with their upper extremities. Similarly, sometimes persons with RA find it difficult to maintain their grip on a cane. These factors affecting the upper extremities might be the reason that the SRPE score was as low as that of the unassisted condition.

Participants could hold a wider area of the service dog using both hands than that of the cane, and the participants could hold their body in a stable way. This may be a major benefit of using the service dog as a supporting tool. Therefore, when standing up with a service dog, the SRPE score was significantly increased compared with that for standing up in the unassisted or cane condition. In the present study, movements of the upper extremities were not evaluated, but I think that future research should be conducted which evaluate the relationship between impairment of the upper extremities and performance with the service dog.

In conclusion, the assistance of a service dog had benefits in standing up for patients with RA. However, due to the variety of movements used, the positioning of the dog to support the coming to stand movement was shown to be important. Further, depending on the impairment of joints in the lower extremities, the most appropriate maneuver to stand up with a service dog should be selected, and training the service dog should be conducted to enable it to learn the best timing of movement to support coming to stand.

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Table 1. Stage and functional classification of the participants in the American College of Rheumatology rating system (ACR) [14].

	ACR stages			
Stage	I	II	III	IV
Number of patients	0	3	12	9
	ACR Functional Classification			
Class	I	II	III	IV
Number of patients	0	10	14	0

Explanation of the ACR Classification Criteria for Determining Progression of Rheumatoid Arthritis

I: EARLY

1. No destructive changed on roentgenographic examination
2. Radiographic evidence of osteoporosis may be present

II: MODERATE

1. Radiographic evidence of osteoporosis, with or without slight sub-chondral bone destruction; slight cartilage destruction may be present.
2. No joint deformities, although limitation of joint mobility may be present
3. Adjacent muscle atrophy
4. Extra-articular soft tissue lesions, such as nodules and tenosynovitis may be present

III: SEVERE

1. Radiographic evidence of cartilage and bone destruction, in addition to osteoporosis
2. Joint deformity, such as subluxation, ulnar deviation, or hyperextension, without fibrous or bony ankylosis
3. Extensive muscle atrophy
4. Extra-articular soft tissue lesions, such as nodules and tenosynovitis may be present

IV: TERMINAL:

1. Fibrous or bony ankylosis
2. Stage III criteria

ACR Classification Criteria of Functional Status in Rheumatoid Arthritis

Class I:	Completely able to perform usual activities of daily living (self-care, vocational, and avocational)*
Class II:	Able to perform usual self-care and vocational activities, but limited in avocational activities
Class III:	Able to perform usual self-care activities, but limited in vocational and avocational activities
Class IV:	Limited ability to perform usual self-care, vocational, and avocational activities

*Self-care activities include dressing, feeding, bathing, grooming, and toileting. Avocational (recreational and/or leisure) and vocational (work, school, homemaking) activities are patient-desired and age- and sex-specific.

Table 2. Service dogs used in the present study.

	Dog A	Dog B
Age (years)	9	5
Sex	Male	Female
Species	Labrador Retriever	Golden Retriever
Size (cm)		
Length	63	60
Height	57	55
Shoulder width	18	18
Hip width	20	17
Training experience as a service dog (months)	10	12

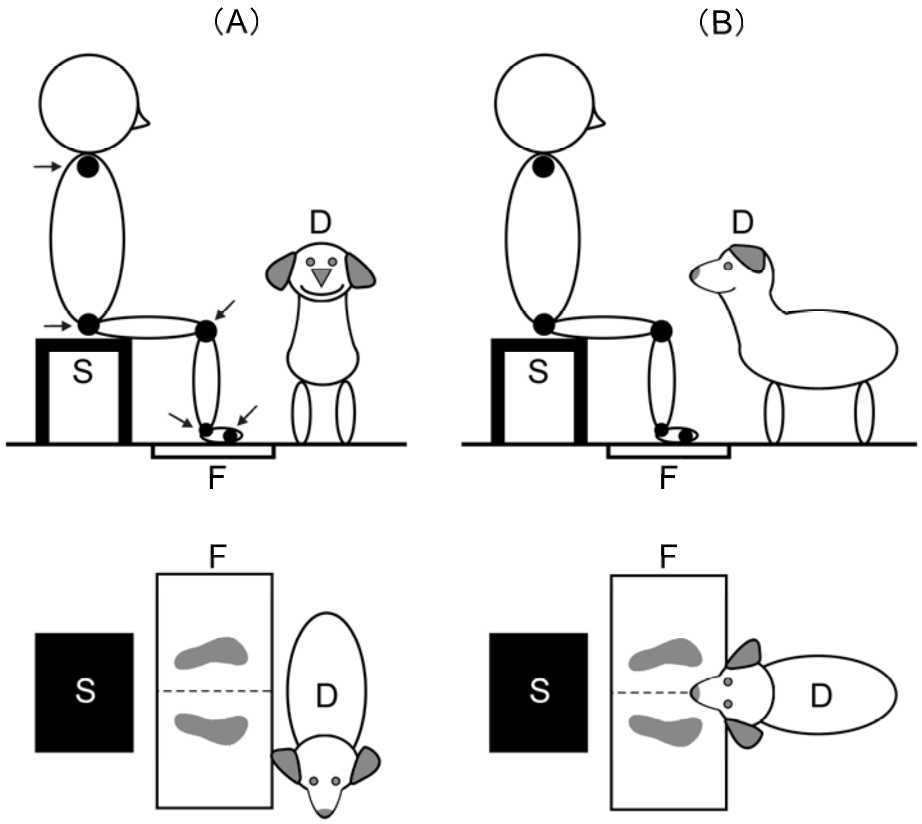

Fig. 1: The experimental setup with positions of a service dog. Participant (S) was seated on a height adjustable chair (C) and force plate (F) in an initial position with joint markers indicated by arrows. Side (A) and front (B) facing positions of a service dog (D).

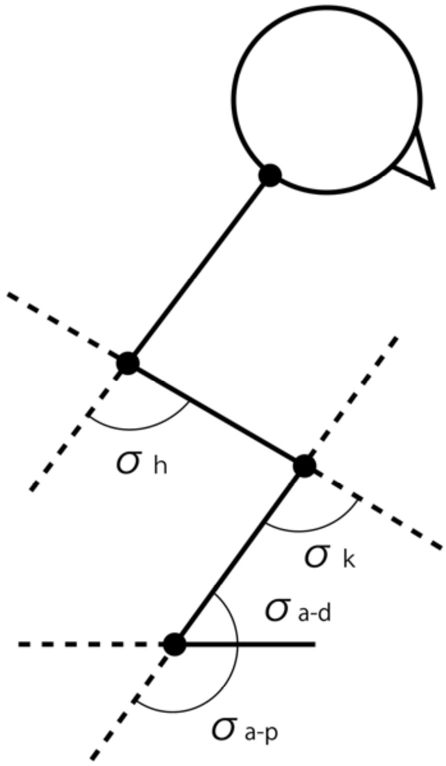

Fig. 2: A schema of seven segments model for analysis, which consists of 2 feet, 2 shanks, 2 thighs and a trunk. Joint angles at hip (σh), knee (σk), ankle dorsiflexion (σa-d) and ankle plantar flexion (σa-p) are shown.

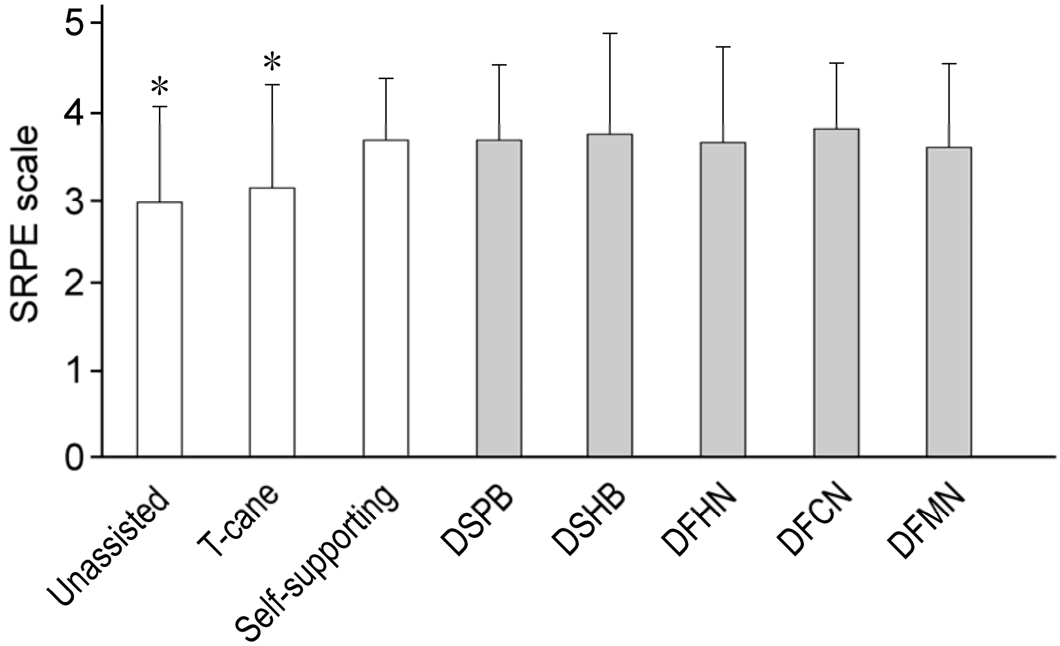

Fig. 3: Mean and standard deviation of the self-rating score on the perceived exertion (SRPE) scale for coming to stand from a seated position transfer movement in each condition (see text). Gray and white columns indicate with and without a service dog conditions, respectively. The scores in conditions with a service dog were significantly higher than those without a dog, unassisted and cane conditions (* $p < 0.05$). Each vertical bar indicates a standard deviation.

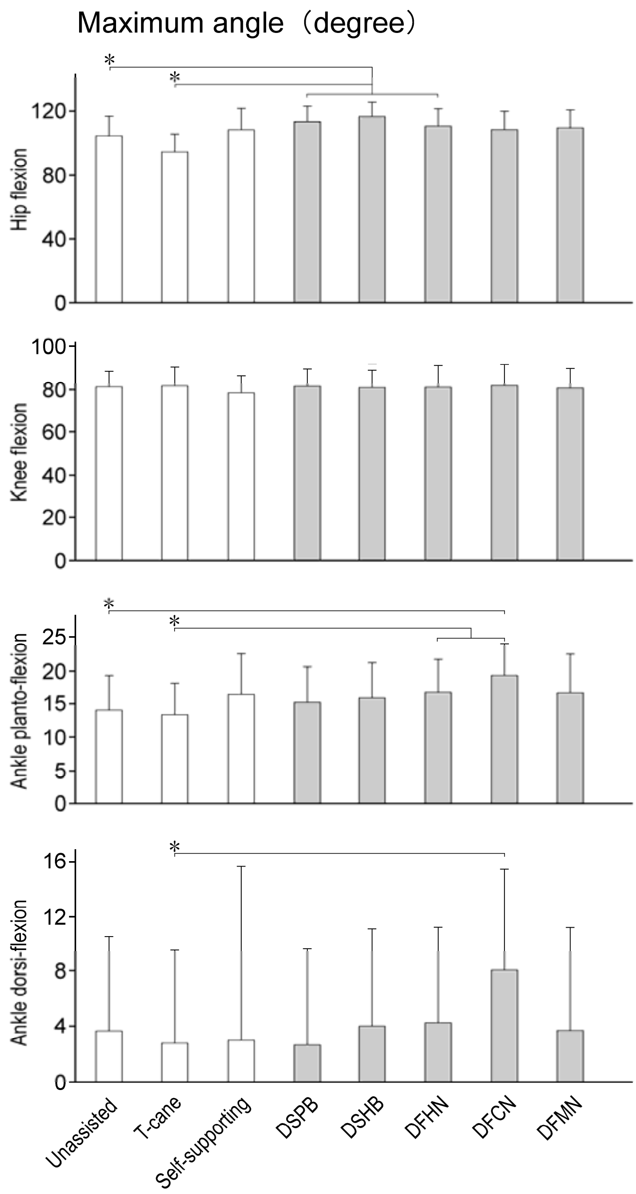

Fig. 4: Mean and standard deviation of the maximal angles of hip flexion, knee flexion, and ankle flexions during standing-up movement in the eight conditions (see text). Gray and white columns indicate with and without a service dog conditions, respectively. Significant differences between conditions were indicated by horizontal lines with asterisks (* $p < 0.05$). Each vertical bar indicates a standard deviation.

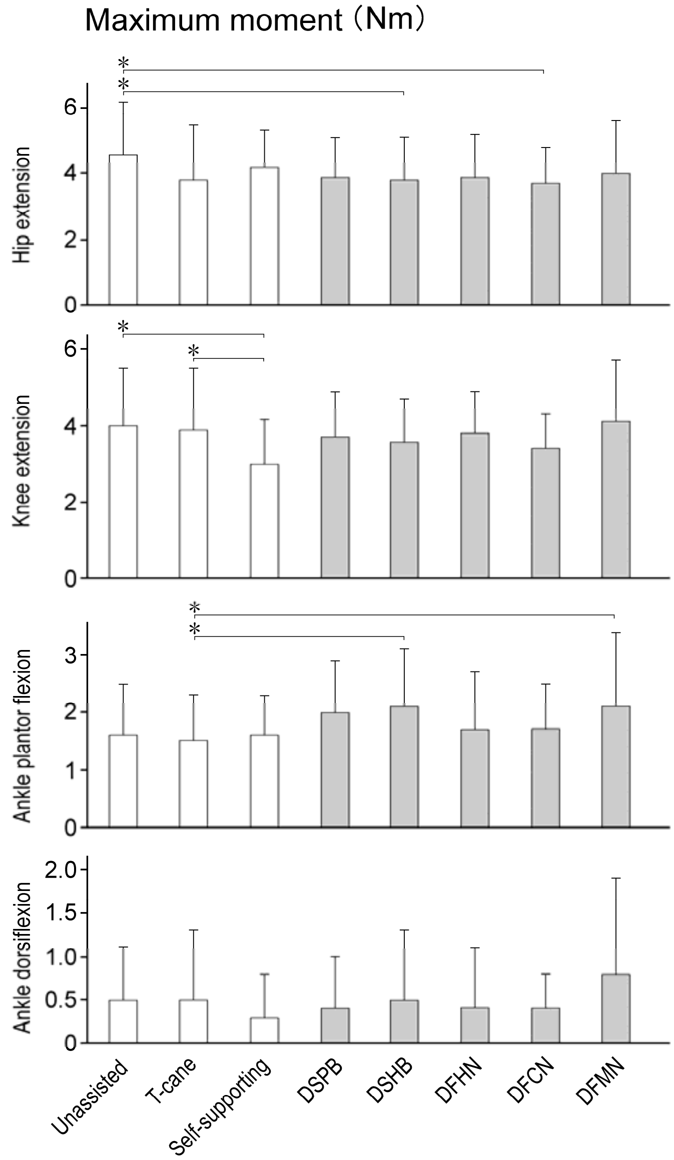

Fig. 5: Mean and standard deviation of the maximal moments of hip extention, knee extension, and ankle flexions during standing-up movement in the eight conditions (see text). Gray and white columns indicate with and without a service dog conditions, respectively. Significant differences between conditions were indicated by horizontal lines with asterisks (* $p < 0.05$). Each vertical bar indicates a standard deviation.

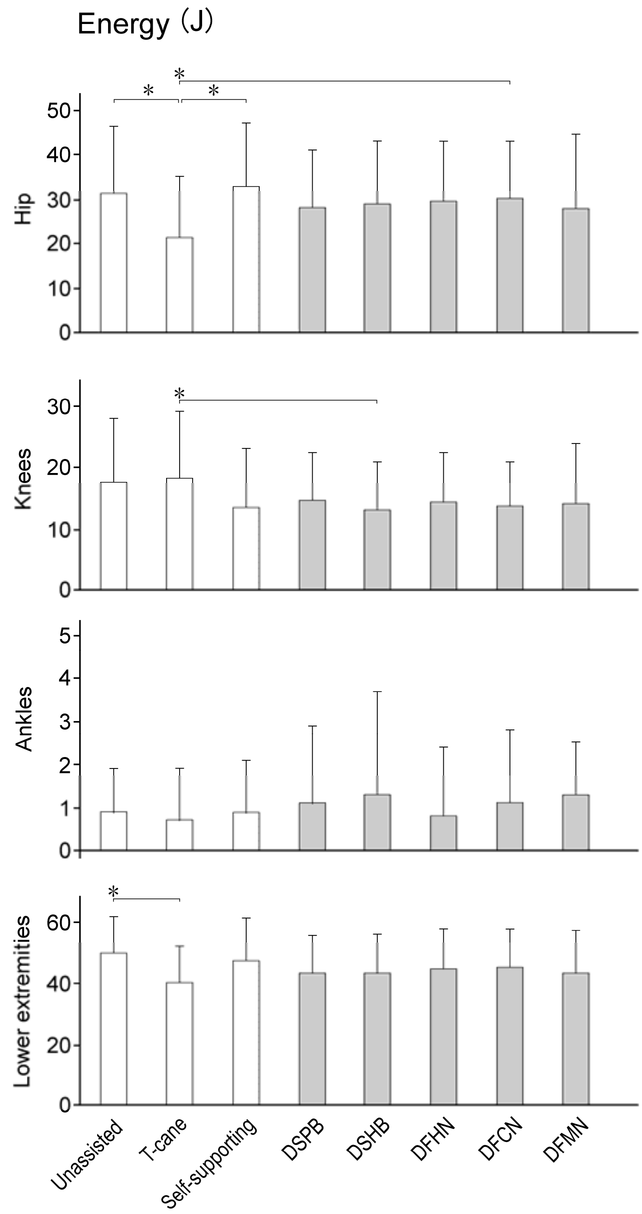

Fig. 6: Mean and standard deviation of the energies required at hip, knee, ankle, and lower extremities during standing-up movement in the eight conditions (see text). Gray and white columns indicate with and without a service dog conditions, respectively. Significant differences between conditions were indicated by horizontal lines with asterisks (* $p < 0.05$). Each vertical bar indicates a standard deviation.

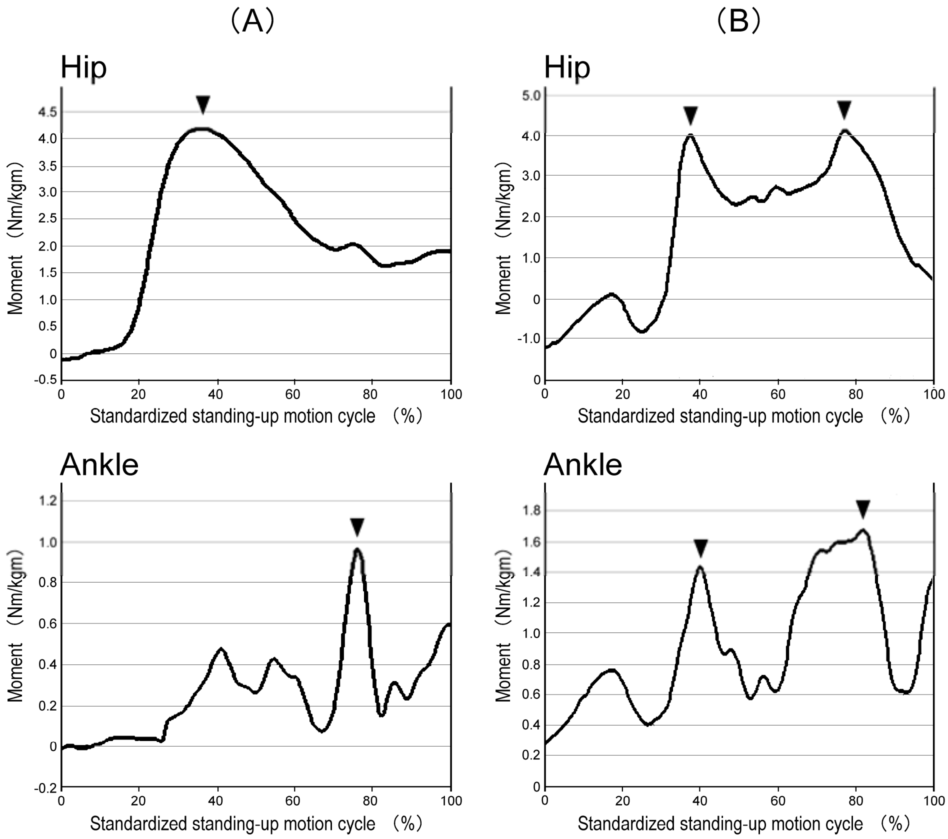

Fig. 7: The moments at hip and ankle joints during stand-up movement in unassisted condition (A) and with a service dog of DSPB condition (B). The result for the unassisted condition shows one peak of the waveform of the moment at the hip and ankle joints. Joint moments showed one major peak during unassisted condition, while they showed two peaks in a condition with a service dog.