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Paper:

# Skill Extraction from Nursing Care Service Using Sliding Sheet

**Qi An**[*,†], **Junki Nakagawa**[**], **Junko Yasuda**[***], **Wen Wen**[*],
**Hiroshi Yamakawa**[*], **Atsushi Yamashita**[*], **and Hajime Asama**[*]

[*]The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
[†]Corresponding author, E-mail: anqi@robot.t.u-tokyo.ac.jp
[**]Recruit Co., Ltd., Tokyo, Japan
[***]No Lifting Association in Japan, Kobe, Japan

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**Back pain has been a serious problem for novice nurses who care for bedridden patients. To avoid back pain, placing a slippery sliding sheet beneath a patient has been suggested so that nurses can pull it when repositioning the patient rather than lifting the patient. However, inappropriate use of the sheet may not reduce lumbar pain. Therefore, it is important to identify skills required for novice nurses to perform bed care movements using a sliding sheet. This study firstly performed interview to obtain useful knowledge from expert nurses who are skilled in using a sliding sheet. Next, a simulation study was then conducted to determine specific bed care movements that would minimize lumbar joint moment associated with lumbar pain. The simulated and expert movements were compared to validate whether expert movements decreases lumbar joint moment. Finally, a novice participant was taught these expert movements, and the educational effect of using these skills was validated. Our results showed that the experts used characteristic movements, keeping the upper arm and trunk stabilized and utilizing a shift in body weight, when performing bed care movements with the sliding sheet. Additionally, the expert movements and simulated movements were shown to be similar. This result confirmed that expert movements could contribute to reducing lumbar joint moments. Moreover, a novice participant could decrease lumbar moment using skills derived from effective education.**

**Keywords:** nursing care service, skill extraction, optimization

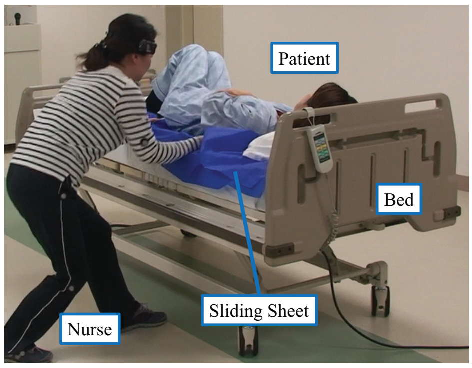



**Fig. 1.** Nursing care motion using the sliding sheet. The figure above shows how the nurse pulls the sliding blue sheet below the patient in order to change the posture.

## 1. Introduction

The elderly population comprises more than 25% of the Japanese population, and the burden on nurses caring for elderly people, including those who are bedridden, is increasing. Approximately between 60% and 70% of people providing care for bedridden patients have lumbar pain due to the nature of their work [1]. When lumbar pain is severe, injured carers require medical treatment, thereby increasing social welfare spending [2, 3]. Therefore, preventing lumbar injuries in people who provide bed care is an urgent issue. Among various care movements, lifting and moving a patient from a bed to a wheelchair poses a particular burden on a nurse's back. To prevent or treat lumbar pain, a method for lifting patients using an exoskeleton robot has been proposed [4], but this method requires additional time and cost expenditure prior to the introduction of the robot. Nurses who used a sliding sheet for assistance when lifting a patient reported a decreased rate of lumbar pain [5]. **Fig. 1** shows the bed care movements of a nurse using a sliding sheet. In this figure, a patient lies on the bed on top of a blue sheet, and the nurse pulls the sheet to change the patient's posture and move the patient to a stretcher or wheelchair placed alongside the bed. A sliding sheet is relatively low priced, and its introduction in medical facilities and ordinary homes is easy. However, the weight load on the nurse's back does not reduce when the sliding sheet is used inappropriately. Therefore, identifying techniques, skills, and appropriate use of the sliding sheet and training novice users to appropriately use the sliding sheet are necessary [6–8]. Here, we identify skills used in bed care movements when using a sliding sheet.

Expert skills have been identified in many different industrial fields. In the field of nursing care, there are several studies on the role of skilled experts. One study determined differences between expert and novice nurses with respect to the manner in which they performed various duties, such as recording blood pressure and heart rate, and how they positioned their patients accordingly [9]. Another study evaluated a patient's movement from a bed to a wheelchair from his/her viewpoint [10]. A further study assessed the methods of nursing care for a patient at home [11]. These studies used a motion capture system with sensors, including a force sensor and inclinometer, video camera, and questionnaire survey to record the nurses' movements. They also focused on specific body parts, such as the lumbar region, to identify the difference between the skills and techniques of expert and novice nurses. Skills and techniques were mostly identified from the movements of expert nurses, and it remains unclear whether these expert nurse skills reduced the burden on lumbar region. To verify the burden reduction effect, it is important to develop a human link model that can simulate motion to reduce lumbar burden and compare the movements with those performed by expert nurses. Park et al. and Lin et al. identified an ideal lifting technique for nursing care movements and compared it with the movement of expert nurses to verify the effectiveness of the technique [12, 13].

In this study, a bed care lifting/moving technique that reduces lumbar burden when using a sliding sheet was identified by using a similar identification method. For this purpose, we focused on the movement of holding the sliding sheet and identified body parts critical for the movement to determine the skilled technique of expert nurses. Next, we developed a human link model and calculated the movements that minimized lumbar burden. By comparing the calculated results and identified skilled technique of expert nurses, we assessed whether the skilled technique was effective in reducing lumbar burden. Finally, we confirmed whether lumbar burden reduced when a novice nurse was taught expert skilled techniques when using this specialized equipment.

## 2. Method

In this study, we focused on sheet-pulling movements performed during bed care. Through an interview with expert nurses, we identified the body parts that played an important role in the movements. We then compared expert and novice nurses to identify the skills and techniques of expert nurses. Next, we developed a human link model and performed optimization calculations to derive a lumbar joint moment. Comparing the movements that minimized lumbar joint moment and movements of expert nurses, we examined whether the skilled technique of expert nurses reduced lumbar joint moment. Finally, we tested to confirm whether lumbar joint moment reduced when a novice participant learned and performed the skilled technique.

### 2.1. Identification of Skill for Bed Care Movements

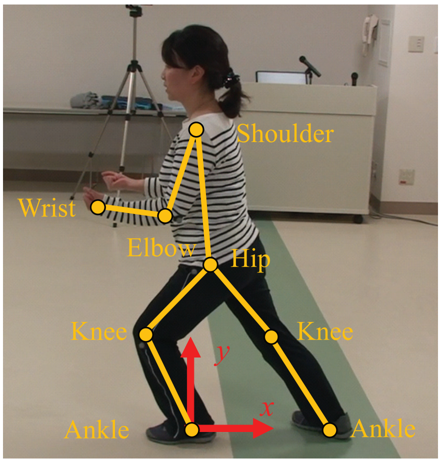
First, we set out a method to identify the skills and techniques of expert nurses, which used for key skills education technology. In particular, because the skilled techniques used in bed care movements should prevent the onset of lumbar pain, the aim of this study was to identify skilled techniques for bed care to reduce lumbar burden.

Here, skill identification was made using a method proposed in a preceding study [14]. Skill identification consists of a phase where preliminary knowledge of the skill to be identified is acquired through an interview and the KJ method, and a phase where evaluation is made through comparing video images of the body motions of novice and expert nurses. In the first phase, we interviewed an expert nurse to obtain information concerning important skills and techniques used in bed care movements. The first phase was conducted using the following steps. First, the nursing care movements of the expert nurse using the sliding sheet were video recorded, as shown in **Fig. 1**. An interviewer accompanied the nurse, observed the nurse's movements, and took note of movement details that were difficult to record using the video camera or the sound recorder. Next, the scene where the expert nurse educated novice nurses concerning the relevant movements was video recorded and observed. The expert nurse was interviewed on the basis of the information collected. The interview was conducted with questions and answers concerning what the expert nurse had said and whether the skills identified from the observation of the interviewer were correct or incorrect.

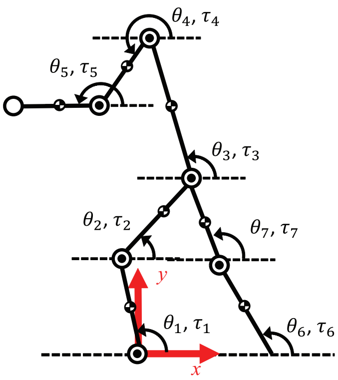
Common elements were extracted from the interview results to organize information regarding the skills and identify key skills using the KJ method. The KJ method involves multiple persons who collate the information data, write the information on slips or cards, and divide the cards into groups for illustrative understanding [15, 16]. Multiple expert nurses, excluding the expert nurse who had been previously interviewed, joined this work to organize bed care skills involving the use of the sliding sheet using the KJ method. In particular, the following three points were considered in the KJ method:

- Bed care movements and movement flow using the sheet
- Skill in the entire movement flow as well as in each movement phase to prevent lumbar pain
- Movements the novice nurses failed to perform

Next, we compared the video images of the expert and novice nurses to identify the key skills and techniques obtained from the interview and from the KJ method, in order to find the differences in the movements between the nurses, and qualitatively evaluate their skills. In this second phase, in addition to the video images taken in the first interview phase, new video images of the critical movements of the expert and novice nurses were taken to identify the key skills that the novice nurses did not have and that the expert nurse considered to be important.

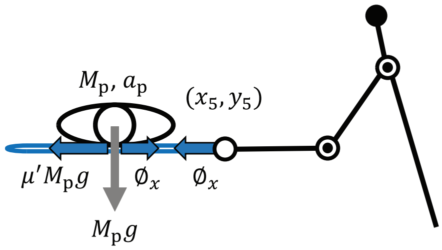



(a) 7-link model

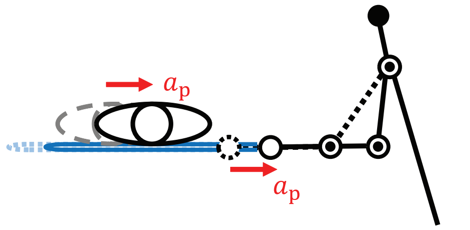



(b) Segment variables

**Fig. 2.** (a) shows the 7-link model used in our study. The human body is divided into shank, thigh, trunk, upper arm, and lower arm regions. (b) shows definition of each of the variables.




(a) Skeletal model to pull sheet




(b) Sheet-pulling motion

**Fig. 3.** Skeletal model to pull the sheet. (a) shows the link model pulls sheet on which a patient lies. Frictional force is generated on the hand (distal end of fifth segment). (b) shows how the link model performs the sheet-pulling motion. The patient also moves according to the sheet movement.

## 2.2. Lumbar Joint Moment Minimization Calculation Based on the Link Model

Here, we developed a human link model and simulated human movement to verify whether the skills identified in Section 2.1 reduced the lumbar burden. The burden on the lumbar region was evaluated in terms of lumbar joint moment, as used in preceding studies [17, 18]. Simulations were performed to find the movements that nurses used to minimize lumbar joint moment, and these were compared with the movements of expert nurses.

The developed link model is shown in **Fig. 2(a)**. Focusing on bed care movements occurring in the sagittal plane, the model expressed human body movement using seven links, namely, the right and left shanks and thighs, the trunk, the upper arms, and the forearms. Given that the nurses pulled the sliding sheet without moving their feet on the floor, the feet of the link model were fixed on the ground. Additionally, given the lumbar position is determined by the rotation angles of the feet and knees, the right and left sides of the pelvis were assumed to be passive joints and the lumbar region was assumed to be an active joint. The parameters of each link are shown in **Fig. 2(b)**. The joint angle $\theta_{k(k=1,\dots,7)}$ shows the angle of the $k$-th link from the horizontal axis and $\tau_k$ shows the moment on the joint. Given the mass, length, center of gravity of the link part including the distal end, and the moment of inertia as parameters of each link, the equation of motion is given by Eq. (1).

$$\mathbf{I}(\Theta)\ddot{\Theta}+\mathbf{h}\left(\Theta,\dot{\Theta}\right)+\mathbf{g}(\Theta)=\mathbf{T}+\Phi. \quad \dots \quad (1)$$

$\mathbf{I}(\Theta)$, $\mathbf{h}\left(\Theta,\dot{\Theta}\right)$, and $\mathbf{g}(\Theta)$ in Eq. (1) show the inertia term; nonlinear term, including the centrifugal force; and gravity term, respectively, and are calculated from Lagrange's equation of motion. $\Theta$ consisting of $[\theta_1, \theta_2, \dots, \theta_7]$ is the joint angle, and $\mathbf{T}$ consisting of $[\tau_1, \tau_2, \dots, \tau_7]$ is the joint torque. $\Phi$ is an external force term and consists of a friction force $\phi_x$. The friction force acts on the distal end (hand) of the forearm ($k=5$) that grasps the sliding sheet when pulling the sheet on which the patient lies. In the bed care movements, it is important to pull the sheet in a direction parallel to the plane of the bed where the patient lies. Therefore, in the simulations, the hands are assumed to move only in the horizontal direction, and only the horizontal friction force is considered. An upper body model pulling the sliding sheet is shown in **Fig. 3(a)**. In the figure, $M_p$ is the mass of a patient on the sheet, $g$ is the gravitational acceleration, $a_p$ is the acceleration of the patient in the $x$-axis direction, and $\mu'$ is the coefficient of dynamic friction of the sheet. The equation of motion gives the force on the forearm, $\phi_x$, as expressed by Eq. (2).

$$\phi_x = M_p\left(a_p-\mu' g\right). \quad \dots \quad (2)$$

Because the features of the patient and the sheet de-

**Table 1.** Parameters in simulation. Segment parameters are shown below.

| $k$ | Segment | Mass [kg] | Length [m] | Mass Center Position [m] | Inertial Moment [kgm$^2$] |
|---|---|---|---|---|---|
| 1, 6 | Shank | 3.07 | 0.22 | 0.13 | 0.011 |
| 2, 7 | Thigh | 7.13 | 0.35 | 0.19 | 0.070 |
| 3 | Trunk | 26.51 | 0.51 | 0.25 | 0.82 |
| 4 | Upper Arm | 1.51 | 0.29 | 0.15 | 0.0087 |
| 5 | Fore Arm | 0.87 | 0.22 | 0.09 | 0.0032 |

**Table 2.** Initial joint angles for optimization.

| | $\theta_1(0)$ | $\theta_2(0)$ | $\theta_3(0)$ | $\theta_4(0)$ | $\theta_5(0)$ | $\theta_6(0)$ | $\theta_7(0)$ |
|---|---|---|---|---|---|---|---|
| Angle [°] | 120.8 | 53.1 | 90.0 | 257.7 | 180.0 | 126.9 | 123.2 |

termine the mass $M_{\mathrm{p}}$ of the patient and the coefficient of dynamic friction $\mu'$, the force on the hand $\phi_x$ is determined only through the horizontal acceleration of the patient $a_{\mathrm{p}}$. In the bed care movements studied here, the patient is moved while lying on the sheet as in **Fig. 3(b)** and the acceleration $a_{\mathrm{p}}$ agrees with the hand motion of the link model. In the simulation, we set in advance the motion of the hand (distal end of link 5) to follow an actual movement performed by the expert nurses, and restricted the variation width $\Delta\theta_k$ of the joint angle in unit time. Then, the combination of $\Theta$ that minimizes lumbar joint moment $\tau_3$ at each time was calculated using nonlinear constrained optimization on the basis of Eqs. (1) and (2). For the calculation, we employed the internal point method algorithm [19–21] using MATLAB.

### 2.3. Training in Bed Care Movement Skills and Techniques

The key skills for bed care movements identified in the preceding section were taught to the novice participants, and their movements were compared before, between, and after a training session to check whether the skill training was effective in reducing lumbar pain. The novice participants pulled the sheet, and the movement was evaluated on the basis of the body trajectory, floor reaction force, and lumbar joint moment. During the training session, the novice participants watched video images of the movements of the expert and novice nurses as well as key skills identified from the interview with the expert nurse, and video image analysis was explained verbally to the novice participants. The novice participants learned the key skills to a suitable standard and pulled the sliding sheet to imitate the movement of the expert nurse.

## 3. Experiments

### 3.1. Skill Identification Experiments

Following the method explained in Section 2.1, we interviewed an expert nurse with 7 years of experience in using a sliding sheet for bed care work, and we asked what skills the nurse considered important when performing bed care using the sheet. Next, two expert nurses with 5 years of experience in using a different sheet from the one used by the interviewed nurse, and two students who were novice nurses organized the skill knowledge information using the KJ method.

An expert nurse and two novice nurses participated in the experiment for video analysis. They virtually pulled a sheet, and video images of their movements were captured using a video camera. The novice nurses were informed only with respect to bed care work using a sliding sheet and not with respect to the skill of the expert nurse.

### 3.2. Simulation Experiments

The parameters of each segment used in the simulation of the developed link model are shown in **Table 1**. For the mass, center of gravity, and moment of inertia of each body link, we referred to Ae et al.'s study [22]. For the length of each link, a value calculated from the measurement data was used. The joint angles of the initial posture used in the simulations were the initial values taken from the movement measurement of the expert nurse, as shown in **Table 2**. Similarly, hand trajectory data were taken from the measurement in a preliminary experiment. We set the patient's weight to 36.0 kg. Assuming the sliding sheet used was made of nylon (Taica Corporation), we set the coefficient of dynamic friction $\mu'$ to as low as 0.20 in the simulation experiments. The time interval was set to 0.05 s, and the optimization calculations were performed for a time period of 3.00 s, which was the time that the expert nurse took for the bed care movements. From the measured movements of the expert nurse, the maximum change of the joint angle in the time width $\Delta t$ was set to 0.57°.

### 3.3. Evaluation Experiments for Identified Skills

Lumbar joint moment was measured after the novice participants learned the identified skills to confirm that there was reduced movement following the training session when the participant pulled the sheet while being conscious of the appropriate skills. A healthy novice participant (age, 23 years; height, 1.73 m; and weight, 70 kg)

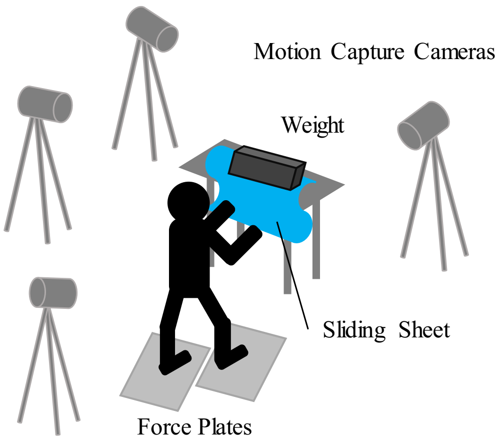
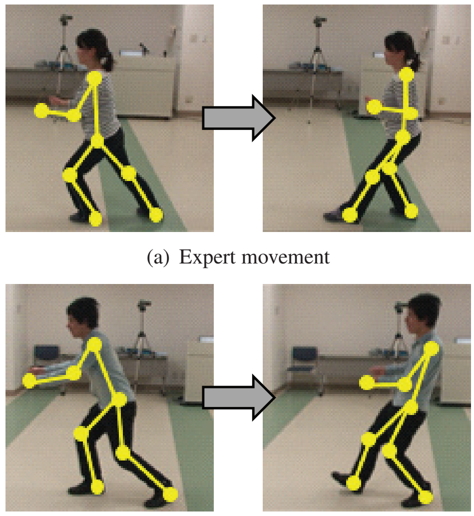



**Fig. 4.** Experimental setup to evaluate the effect of skill education. The figure above indicates the measurement experimental setup. It consists of motion capture cameras and force plates to record the body trajectory and the reaction force, respectively. The participant was asked to pull a sliding sheet on which the weight was put.



(a) Expert movement

(b) Novice movement

**Fig. 5.** This figure shows the video to record (a) expert and (b) novice movement. Compared to the novice movement, the expert nurse maintains her trunk vertical to the ground, bends the arms to keep them close to her trunk, and utilizes her body weight shift.

performed the experiment. The experiment situation is shown in **Fig. 4**. In the experiment, the novice participant was instructed not to completely extend his arms or stand too close to the sheet when holding the sheet. Then, the subject was asked to perform the action until the sheet was completely pulled from under the patient. During the pulling movement, body trajectory was measured at 200 Hz using an optical motion capture system (Motion Analysis) with a Helen Hayes marker set. In addition, the reaction forces from the floor to the nurse's feet were measured using a 6-axis reaction force sensor (Nitta) at a sampling rate of 64 Hz. Based on the measured body trajectory and floor reaction force data, a whole-body musculoskeletal model (Musculographics, SIMM) was used to calculate lumbar joint moment. The experiments of this study were conducted with the approval of the Ethics Committee at the School of Engineering, The University of Tokyo.

## 4. Results and Discussions

### 4.1. Results of Skill Identification

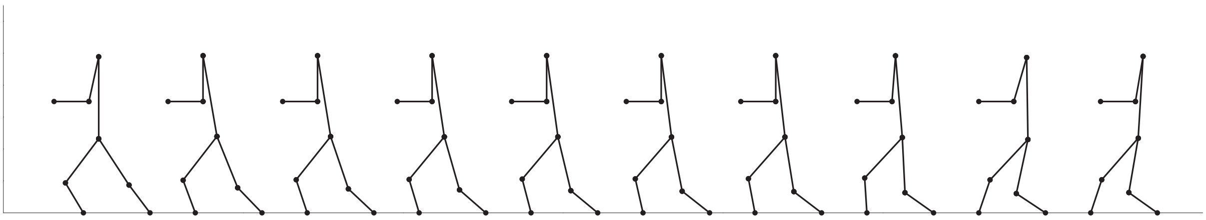
After interviewing the expert nurse and applying the KJ method to the interview, we classified forty opinions obtained with respect to sheet-pulling movements, details that the expert nurse considered important in each phase of the movement, and general details that the expert nurse considered important. From the results, we identified the following three skills:

- Upper body: The posture remained unchanged as much as possible before, between, and after pulling the sheet.
- Upper arms: The upper arms were kept vertical to the ground.
- Legs: The sheet was pulled not by the arms but when moving the legs and trunk to make a weight shift.

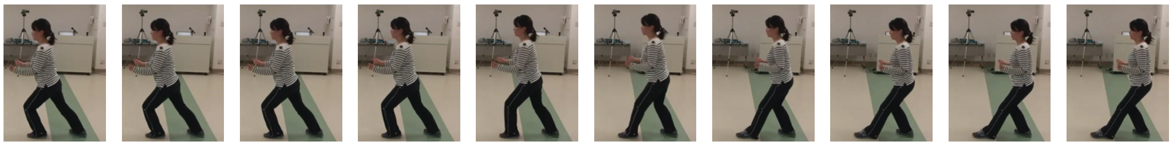
**Figure 5** shows the movements of the expert and the novice recorded on video images. This figure shows their postures at the start and end of the movements. We focused on three key skills involving movements of the trunk, upper arm, and legs. We compared the sheet-pulling movements between the expert and the novice and found that the novice began movements with the trunk tilted forward, followed by tilting the trunk backward, whereas the expert nurse had limited variation in the trunk posture throughout the movements. Regarding the movements of the upper arms, the novice grasped the sheet with extended arms and pulled the sheet, largely by moving the arms backward, whereas the expert nurse kept the arms bent and positioned close to the trunk during the sheet-pulling movements. Moreover, the novice used arm force to pull the sheet with legs extended, with a high positioned center of gravity. On the other hand, the expert nurse lowered the body and shifted the weight backward. We found that the difference in the skill and technique between the expert and the novice was related to the expert nurse maintaining the upper body posture, keeping the elbows bent, and making the weight shift with the body lowered.

### 4.2. Simulation Results

**Figure 6(a)** shows time series data of the movements that minimized lumbar joint moment derived in the optimization calculations. **Fig. 6(b)** shows the video images of the expert nurse. Comparing their movements, we observed that the angles of the arm and upper body changed little and movements were mostly made using the legs by

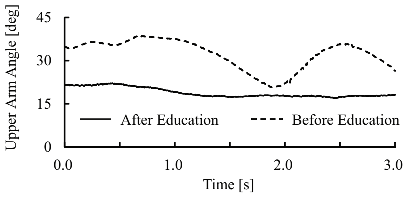


(a) Optimized sheet-pulling movement

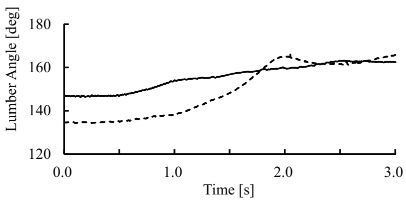


(b) Sheet-pulling movements of the expert nurse

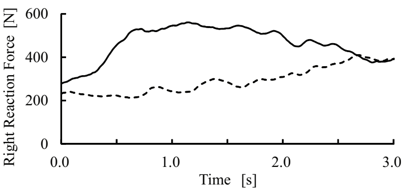
**Fig. 6.** (a) The stick figures above show optimized movement to minimize lumbar joint torque. (b) The pictures above show the sheet-pulling movement of the expert nurse. These two figures show that the expert nurse's movements and simulated movements are similar.



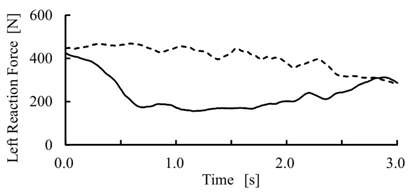

(a) Upper arm angle



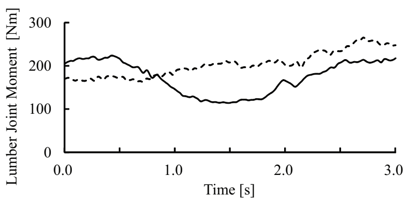

(b) Lumber joint angle




(c) Right reaction force




(d) Left reaction force




(e) Lumber joint moment

**Fig. 7.** Effect of skill education. The figures above show a comparison of education effect on (a) the upper arm joint angle, (b) the lumber angle, (c) the right reaction force, (d) the left reaction force, and (e) the lumber joint moment. These show that trainees were able to learn the expert skill technique performed to decrease lumbar joint moment.

the expert nurse. This indicated that the skill and technique of the expert nurse had effectively reduced the burden on the lumbar region.

### 4.3. Results of the Skills Training Session

In the skills training session, video images of the expert nurse's movements taken in Section 3.1 were shown to the novice participant and the identified skills were verbally explained to them. The movements of the novice participant were compared before, between, and after the training session, and the identified key skills, namely, the angle of the trunk, the angle of the upper arms, and the weight shift of the legs, were observed to check if the novice participant was able to follow the movements of the expert nurse. The result is shown in **Fig. 7**. **Fig. 7(a)** shows the angle changes of the upper arm before and after the training session. Before the training session, the angle of the upper arm largely changed, whereas it remained stable after the training session. **Fig. 7(b)** shows the angle change of the upper body. Also in this figure, the angle change was smaller after the training session than before, and the angle was kept almost constant. The changes of the floor reaction force in the right and left feet are shown in **Figs. 7(c)** and **(d)**, respectively. The change of the floor reaction force was larger after the training session than before, which indicates that the novice participant, having learned the skills and techniques, pulled the sheet using the shift in weight and not using arm force. The lumbar joint moment before and after the training session is shown in **Fig. 7(e)**. In the sheet-pulling movement, the sliding sheet on which the patient lay is continuously pulled, and hence, the lumbar joint moment needs to decrease continuously during the movement. The overall lumbar joint moment after the training session increased at the start of the movement due to the difference in the initial posture, but decreased afterwards from the moment measured before the training session. This indicated that the appropriate angle of the upper arms and trunk and the weight shift of the lower limbs contributed to the prevention of the lumbar pain.

## 5. Conclusions

Bed care movements using a sliding sheet are necessary to prevent lumbar pain in nurses providing bed care. In this study, a comparison of expert and novice nurses showed that the expert nurse pulled the sheet with the upper arm and trunk kept as stable as possible using the legs to shift weight. We developed a 7-link model and performed optimization calculations to identify the movements that minimized lumbar joint moment. The movements created from the simulations were similar to the video-recorded movements of the expert nurse, and it was found that the skill and techniques used to move the upper arms, trunk, and legs were important to reduce the burden on the lumbar region. In addition, teaching the skills and techniques the novice participant reduced lumbar joint moment, which indicated that lumbar pain could be prevented. The present study performed simulations focusing only on the lumbar region. For future studies, it is important to examine the movements of expert nurses further by minimizing the total torque at all joints and performing optimization calculations that considered individual skills as a reference. Moreover, in future studies, the bed care movements of expert nurses using the sliding sheet should be measured and compared quantitatively with simulation results, and the bed care movements of novice nurses who learn the skills should be evaluated.

**Acknowledgements**

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**Name:**
Qi An

**Affiliation:**
Assistant Professor, Department of Precision Engineering, Graduate School of Engineering, The University of Tokyo

**Address:**
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

**Brief Biographical History:**
2012-2015 JSPS Research Fellowship (DC1)
2014 Received Ph.D. degree from The University of Tokyo
2015- Visiting researcher, RIKEN
2015- Assistant Professor, Department of Precision Engineering, The University of Tokyo

**Main Works:**
• Q. An, Y. Ishikawa, J. Nakagawa, H. Oka, H. Yamakawa, A. Yamashita and H. Asama, "Measurement of Just Noticeable Difference of Hip Joint for Implementation of Self-efficacy: In Active and Passive Sensation and Different Speed," Advanced Robotics, Vol.28, No.7, pp. 505-515, 2014.
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**Membership in Academic Societies:**
• Institute of Electrical and Electronics Engieers (IEEE)
• Robotics Society of Japan (RSJ)
• Soceity of Instrument and Control Engineers (SICE)
• Japan Society of Mechanical Engineers (JSME)
• Japan Society for Precision Engineering (JSPE)

**Name:**
Junki Nakagawa

**Affiliation:**
Team Leader, Recruit Co., Ltd.

**Address:**
Hulic Ginza 7-chome Bldg. 3F, 7-3-5 Ginza, Chuo-ku, Tokyo 104-0061, Japan

**Brief Biographical History:**
2015 Received M.E. degree from The University of Tokyo
2015-2017 Recruit Holdings Co., Ltd.
2018- Recruit Co., Ltd.

**Main Works:**
• J. Nakagawa, Q. An, Y. Ishikawa, H. Oka, K. Takakusaki, H. Yamakawa, A. Yamashita, and H. Asama, "Analysis of Human Motor Skill in Dart Throwing Motion at Different Distance," SICE J. of Control, Measurement, and System Integration, Vol.8, No.1, pp. 79-85, 2015.

**Name:**
Junko Yasuda

**Affiliation:**
Chairman, No Lifting Association in Japan

**Address:**
4-2-8 Isobe-dori, Chuo-ku, Kobe, Hyogo 651-0084, Japan

**Brief Biographical History:**
2001- Registered Nurse
2008- Chairman, No Lifting Association in Japan
2013-2015 The member of the Committee of the Development Assessment System for the Assistive Technology in Kobe
2014-2015 The member of the Preventing Nurses Back Injury Program Committee in the Associative for Technical Aide in Japan

**Main Works:**
• J. Yasuda, "Challenging for preventing care workers' back injury by No Lifting Association in Japan," J. of Japan Society of Occupational Health, Vol.59, No.KS15-3, p. 234, 2017.
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**Membership in Academic Societies:**
• Robotics Society of Japan (RSJ)
• Japanese Nursing Association (JNA)
• Japan Society for Occupational Health (JSOH)
• Japanese Society for Social Medicine

**Name:**
Wen Wen

**Affiliation:**
JSPS Postdoc Researcher, Department of Precision Engineering, Graduate School of Engineering, The University of Tokyo

**Address:**
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

**Brief Biographical History:**
2012-2014 Doctoral Researcher, Advanced Research Centers, Keio University
2014-2016 Project Researcher, Department of Precision Engineering, The University of Tokyo
2016- Honorary Research Associate, Institute of Cognitive Neuroscience, University College London
2017- JSPS Postdoc Researcher, Department of Precision Engineering, The University of Tokyo

**Main Works:**
• W. Wen and P. Haggard, "Control changes the way we look at the world," J. of Cognitive Neuroscience, Vol.30, No.4, pp. 603-619, 2018.

**Membership in Academic Societies:**
• Japanese Psychonomic Society (JPS)
• Society for Serviceology (SfS)

**Name:**
Hiroshi Yamakawa

**Affiliation:**
Senior Technical Specialist, Department of Precision Engineering, The University of Tokyo

**Address:**
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

**Brief Biographical History:**
1992- Technical Official, Faculty of Engineering, The University of Tokyo
1998- Technical Specialist, Graduate School of Engineering, The University of Tokyo
2006 Received Ph.D. degree from The University of Tokyo
2014- Senior Technical Specialist, Graduate School of Engineering, The University of Tokyo

**Main Works:**
- H. Yamakawa, H. Hosaka, I. Kobayashi, and K. Itao, "Approximate Analysis for Airflow Damping of Microoscillator: Analysis by Cylinder Model," J. of the Japan Society for Precision Engineering, Vol.72, No.6, pp. 796-803, 2006.
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**Membership in Academic Societies:**
- Robotics Society of Japan (RSJ)
- Society of Instrument and Control Engineers (SICE)
- Japan Society for Precision Engineering (JSPE)
- Institute of Electronics, Information and Communication Engineers (IEICE)

**Name:**
Atsushi Yamashita

**Affiliation:**
Associate Professor, Department of Precision Engineering, The University of Tokyo

**Address:**
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

**Brief Biographical History:**
2001 Received Ph.D. degree from The University of Tokyo
2001-2008 Assistant Professor, Department of Mechanical Engineering, Shizuoka University
2006-2007 Visiting Associate, California Institute of Technology
2008-2011 Associate Professor, Department of Mechanical Engineering, Shizuoka University
2011- Associate Professor, Department of Precision Engineering, The University of Tokyo

**Main Works:**
- A. Yamashita, T. Arai, J. Ota, and H. Asama, "Motion Planning of Multiple Mobile Robots for Cooperative Manipulation and Transportation," IEEE Trans. on Robotics and Automation, Vol.19, No.2, pp. 223-237, 2003.
- R. Kawanishi, A. Yamashita, T. Kaneko, and H. Asama, "Parallel Line-based Structure from Motion by Using Omnidirectional Camera in Texture-less Scene," Advanced Robotics, Vol.27, No.1, pp. 19-32, 2013.

**Membership in Academic Societies:**
- Institute of Electrical and Electronics Engineers (IEEE)
- Association for Computing Machinery (ACM)
- Robotics Society of Japan (RSJ)
- Japan Society of Mechanical Engineers (JSME)

**Name:**
Hajime Asama

**Affiliation:**
Professor, Department of Precision Engineering, Graduate School of Engineering, The University of Tokyo

**Address:**
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

**Brief Biographical History:**
1986- Research Associate, RIKEN (The Institute of Physical and Chemical Research)
1998- Senior Scientist, RIKEN (The Institute of Physical and Chemical Research)
2002- Professor, Research into Artifacts, Center for Engineering (RACE), The University of Tokyo
2009- Professor, Graduate School of Engineering, The University of Tokyo

**Main Works:**
- Y. Ikemoto, T. Miura, and H. Asama, "Adaptive Division-of-Labor Control Algorithm for Multi-robot Systems," J. Robot. Mechatron., Vol.22, No.4, pp. 514-525, 2010.

**Membership in Academic Societies:**
- International Society for Intelligent Autonomous Systems
- Institute of Electrical and Electronics Engineers (IEEE)
- International Federation of Automatic Control (IFAC)
- Japan Society of Mechanical Engineers (JSME)
- Robotics Society of Japan (RSJ)