



Motion Analysis of Simulated Patients During Bed-to-Wheelchair Transfer by Nursing Students and Skill Acquisition Based on the Analysis

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Abstract. The aging population in Japan is currently at 26.7% and is projected to reach 30.3% by 2025. This points to an increase in nursing care that involves transferring in and out of a wheelchair. Previous research has shown that the way a caregiver embraces the patient when transitioning her from bed to wheelchair contributes to lower back pain and has necessitated educational intervention to prevent occupational back pain. On the other hand, the patient is required to transfer into a wheelchair without falling and to maintain a seated position with the appropriate amount of body pressure. Both caregiver and receiver are asked to act in ways that are safe for both sides when transferring. In our own motion analysis of wheelchair transition, the non-experts bent forward more at the cervical and lumbar spine than the experts, creating greater body pressure distribution due to a smaller area of physical contact with the simulated patient. These results suggest that actions used for bed-to-wheelchair transferring influenced the seated position of the simulated patient. However, there are very few motion analysis studies that examine the patients' movements during a wheelchair transfer. Therefore, this study is based on a motion analysis of the simulated patients while they are being transferred from bed to wheelchair. The study involves 4 nursing students who completed their practical training, and 2 expert nurses. The goal of this study is to turn into explicit knowledge and quantify the tacit techniques of position changing performed in nursing care. Results of this study show that the simulated patients transferred by the non-experts were led through the seating phase faster than those transferred by the experts, and the increase in speed was related to the nurses' proximity to their simulated patients. Furthermore, we learned that motion analysis could be applied to skill acquisition.

Keywords: Motion analysis · Wheelchair transferring · Back pain · Acceleration Interface pressure

1 Introduction

According to the World Health Organization (WHO), the aging rate is defined as the percentage of elderly people aged 65 and over in relation to the total population. Furthermore, a society where the aging rate exceeds 7% is defined as an “aging society”, that with over 14% as an “aged society”, and that with over 21% is defined as a “super aging society” [1]. Japan became an aging society in 1970, and it became a super aging society in 2007. It has the highest aging rate in the world. The total population of Japan in 2014 was 127.08 million, and the number of elderly population was 33 million, the highest ever recorded, and its aging rate became 26.0%. It is estimated that by 2060, one out of 2.5 people will be 65 or over 65, further acceleration in the aging rate is expected [2].

Following the start of the super aging society in Japan, the number of the people aged 65 and over certified to require care reached 5.457 million by 2012, and this number has been increasing year by year. It resulted that the national medical expenses scored 40 trillion yen in 2014, and the cost required for the people aged 75 and over increased to about 11.5 trillion yen [3]. Moreover, by 2025, the national medical expenses for the elderly is expected to reach about 60% of the total medical expenses in Japan. The average health expectancy in Japan is 74.9, which is the highest in the world. In order to control the medical expenses for elderly people, it is necessary to maintain the health expectancy [4]. Sustainable Development Goals of WHO states as, “Ensure healthy lives and promote wellbeing for all at all ages”, and it is required to maintain the healthy lives of elderly people at medical facilities, care facilities and private homes. The preventing the occurrence of sarcopenia or frailty is one of important factors to prevention of being bedridden. It is predicted that there will be further increase of transfer care by medical professionals, care workers and family members.

It is reported that transfer assistance causes lower back pain of nurses. Compare to the 43% occurrence rate in the UK [5] and 40–50% occurrence rate in the US [6], Japan has a high occurrence rate of 60% [7]. Especially the motion of holding and transferring patients to wheelchairs is proven to cause the lower back pain of nurses. It is reported that the factors of the high occurrence rate of lower back pain in Japan includes the lack of progress in prevalence of welfare equipment, assisting tools and educational training [8]. On the other hand, it is necessary to transfer patients safely to wheelchairs without them falling, and then to maintain their seated position with ensuring proper distribution of body pressure. Thus, a wheelchair transfer motion is required to be safe and easy for both a nurse and patient. However, as lower back pain prevention measures are not included in the transfer assistance trainings at nursing colleges, and studies that compare the transferring motions of experts and non-experts are extremely rare, further examination is required regarding the training of non-experts.

In the past motion analysis of wheelchair transfer we conducted, it was clarified that nursing students (non-experts) bent forward more at the cervical and lumbar spine than the nurses (experts), which made the sitting position the simulated patient (SP) shallower on the wheelchair, and resulted in greater body pressure of physical contact between the non-expert and the simulated patient (SP) [9]. This result suggested that the difference in wheelchair transfer motions among caregivers influences the contact area pressure and body pressure of SP when seating. The rule of the body mechanics encourages to

“conduct in an appropriate movement speed” [10]. However, there are few studies that researched how the difference in wheelchair transfer motions between the expert and the non-expert affects the acceleration of SP. Thus, this study aims to clarify the influence of differences in wheelchair transfer motions between the expert and the non-expert on the acceleration of SP, for explicating the tacit knowledge hidden behind the nursing skill for body position change.

2 Methods

2.1 Participants

The participants were 4 students with four years of study in a university nursing science department with nursing clinical training and basic nursing course, and 2 certified nurses who have at least 20 years of experience.

The nursing students were called the non-experts, and the certified nurse were called the experts. The simulated patient (SP) was 1 healthy adult (Table 1).

Table 1. Attributions of participants.




		Expert (N = 2) Mean (SD)	Non-expert (N = 4) Mean (SD)	Simulated patient (N = 1) Mean (SD)
Age		49.5 (3.5)	21.8 (3.0)	24.0
Gender	M	0	2	1
	F	2	2	0
High (m)		1.6 (0)	1.7 (0.2)	1.7
Body mass index		24.1 (4.6)	21.0 (2.7)	20.8

2.2 Procedure

The movements to be studied were the transfer from bed to wheelchair. We used a height-adjustable bed that allowed the SP to sit in the center of the side frame of the bed with the soles of his feet touching the floor. The scenario was that the patient is unable to stand on his own and requires full nursing care. The participants were briefed on the conditions of the SP and were asked to transfer him from the bed to the wheelchair. As for the positions of the bed and the wheelchair, the latter was placed facing 30° toward the bed, with a slight adjustment to make the transition of the SP a little easier. As for the wheelchair transfer motions, we measured movements of each participant twice per single motion. We had a chair ready for the participants to rest if they got tired.

The bed-to-wheelchair motion was categorized into three phases. The first is “standing phases”. The second is “assisting with direction change”. And the third is “assisting to sit in the wheelchair,” which covers the movement from the lowest point of the participant's hips while helping with sitting to the end of the seated position of the participant. These motions were analyzed, and each participant’s phase was contrasted against the other (Table 2).

Table 2. Motion categories of transfer assistance motion from bed to wheelchair.

Motion Categories		Scene	
1	Standing Phase	1) The point at which assistance starts. 2) The lowest point of the participant's hips while assisting standing. 3) The point at which standing ends.	
2	Turning Phase	1) The point at which direction changes.	
3	Seating Phase	1) Point at which the participant's hips are at the lowest point while assisting sitting down. 2) The point at which sitting ends.	

2.3 Recording Procedures

The reflector markers were attached to the body surface and movement during transfer assistance was recorded by six cameras to record 3-dimensional footage. Reflector markers were attached to the subject as shown in Fig. 1: The model had attachments on the head (top, front, right, left), neck (cervical nerve 7), shoulders, top, middle (lumbar nerve 5), trochanter major (TRO), elbows, wrists, thighs, knees, shins, ankles and toes (Fig. 1).

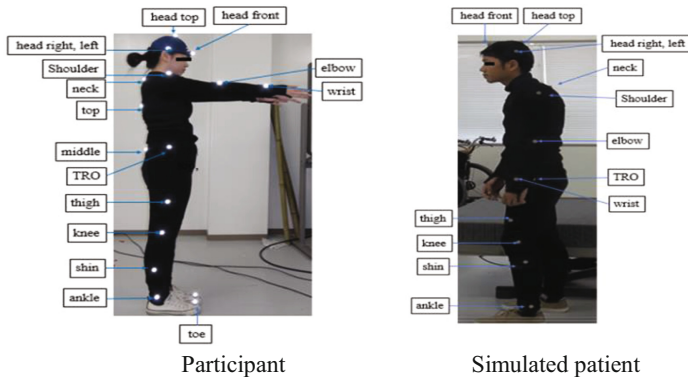


Fig. 1. The attached locations of the reflector markers.

The reflector markers were attached on his head front, neck (cervical nerve 7), shoulders, trochanter major (TRO), elbows, wrists, thighs, knees, shins, ankles and toes (Fig. 1).

For this research, we didn't attach reflective markers to the abdominal area since the patient would block the view. Instead, reflective markers were attached to the back of

the participants to achieve a 3-dimensional analysis. The participants' movements that were assisting the patient from a seated position to the wheelchair. We used a MAC 3D System (motion analysis), sampling rate 100 Hz, creating stick figures to perform a three-dimensional motion analysis. The software was EvaRT Ver. 5.0.4 (motion analysis). We used it to calculate the participant's angle, acceleration per motion, as well as the time it took for each movement.

The section for acceleration measurement was chosen to be the head front section, as any stick picture data would not be missed from both the caregivers and the SP, and the transition data of acceleration during wheelchair transfer motions was collected. The interface pressure measurement sheet was set on the wheelchair to measure the interface pressure. ABW GmbH, ERGOCHECK was used for the interface pressure measurement.

2.4 Data analysis methods

As there was no normality in the statistical certification of each entry, Mann-Whitney's U test was used and the significant standard was set as 5% or less. SPSS for windows 21.0 J was used as the statistical analysis software. Each measurement value was expressed in mean \pm standard deviation (mean \pm SD).

3 Results

Following is the report regarding the results of the comparison between the experts and the non-experts of their cervical spines, lumbers, knees and elbow joints angles, transfer time, distance, acceleration and body pressure distribution during the wheelchair transfer.

3.1 Comparison Between the Experts and the Non-experts of Their Cervical Spines, Lumbers, Knees and Elbow Joints Angles During the Wheelchair Transfer

Table 3 shows the average angles of cervical spines, lumbers, knees and elbow joints angles during the wheelchair transfer (Fig. 2). The cervical spine angle of the experts was 170.2 (SD 9.6) degree ($^{\circ}$) on the average and those of the non-experts was 159.1 (SD 8.5) $^{\circ}$ on the average. The non-experts flexed more toward the front than the experts at statistically significant level ($p < 0.001$). The lumber angle of the experts was the average 120.4 (SD 10.3) $^{\circ}$, and those of the non-experts was the average 113.8 (SD 22.7) $^{\circ}$. The non-experts flexed more than the experts at statistically significant level ($p < 0.001$). The knee angle of the experts was the average 141.6 (SD 19.8) $^{\circ}$, and those of the non-experts was the average 154.5 (SD 17.1) $^{\circ}$. The experts flexed more than the non-experts with statistically significant level ($p < 0.001$). The elbow joints angle of the experts was the average 125.6 (SD 40.8) $^{\circ}$, and those of the non-experts was the average 95.5 (SD 42.4) $^{\circ}$. The non-experts flexed more than the experts at statistically significant level ($p < 0.001$).

Table 3. Comparison between the experts and the non-experts of their cervical spines, lumbers, knees and elbow joints angles during the wheelchair transfer.

Angle (degree)	Expert (N = 2) Mean (SD)	Non-expert (N = 4) Mean (SD)	p
Cervical spine	170.2 (9.6)	159.1 (8.5)	<0.001
Lumber	120.4 (10.3)	113.8 (22.7)	<0.001
Knee	141.6 (19.8)	154.5 (17.1)	<0.001
Elbow	125.6 (40.8)	95.5 (42.4)	<0.001



Fig. 2. Comparison of joints angles between the experts and the non-experts at the end of turning.

3.2 Comparison of SP Wheelchair Transfer Time by the Experts and the Non-experts

The average time those the experts required for wheelchair transfers was 14.6 (SD 6.5) s (Table 4). Looking at the time required for each segment, the experts took 8.0 (SD 3.7) s during the standing phase, 4.3 (SD 2.1) s during the rotating phase, and 2.3 (SD 0.7) s during the seating phase. The average times those the non-experts required for wheelchair transfers was 10.2 (SD 2.3) s. Looking at the time required for each segment, the non-experts took 5.0 (SD 1.1) s during the standing phase, 3.1 (SD 2.2) s during the rotating phase, 2.1 (SD 1.0) s during the seating phase. Both the experts and the non-experts required most time during the standing phase, followed by the rotating and the

Table 4. Comparison of SP transfer time from the rotating phase to the seating phase between the experts and the non-experts.

Motion categories time (sec)	Expert	Non-expert
	(N = 2) Mean (SD)	(N = 4) Mean (SD)
Standing phase	8.0 (3.7)	5.0 (1.1)
Turning phase	4.3 (2.1)	3.1 (2.2)
Seating phase	2.3 (0.7)	2.1 (1.0)

seating phases. There was no statistically significant difference between the wheelchair transfer times of the experts and the non-experts ($p = 1.00$).

3.3 Comparison of the Distance to SP During the Wheelchair Transfer by the Experts and the Non-experts

The distance from the head front of the experts and the head front of SP was 305.2 (SD 62.2) mm, and those of the non-experts was 322.9 (37.9) mm. The distance of the experts was closer to SP than the non-experts with statistical significance (Table 5).

Table 5. Comparison of the average distance to SP during the wheelchair transfer by the experts and the non-experts.

Participants	Expert (N = 2) Mean (SD)	Non-expert (N = 4) Mean (SD)	p
Distance of head front (mm)	305.2 (62.2)	322.9 (37.9)	<0.001

3.4 Comparison of the Average Accelerations Between the Experts and the Non-experts

The acceleration average of the experts and non-experts was calculated for each motion category, and X axis was set as time and Y axis was set as acceleration for the acceleration graph. The accelerations of the experts, the non-experts and SP repeated plus and minus values alternately, conducting reciprocating motions (Figs. 3 and 4).

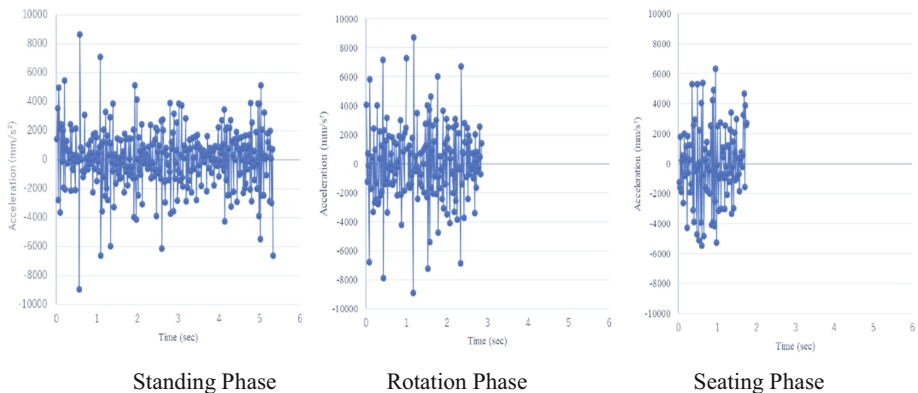


Fig. 3. The acceleration of the expert A.

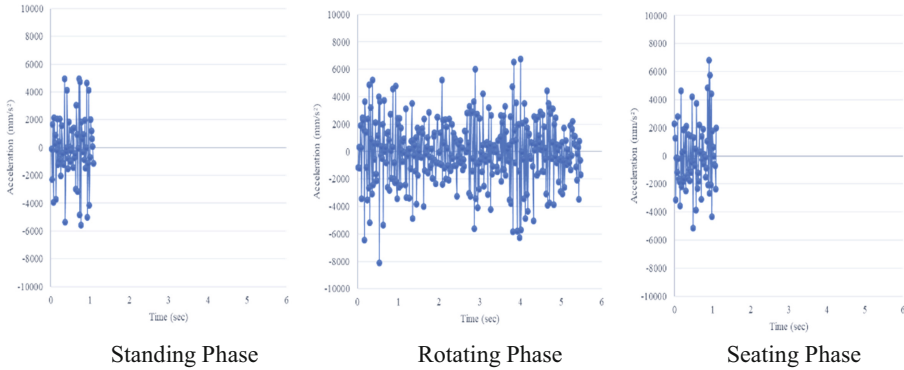


Fig. 4. The acceleration of the non-expert B.

The average acceleration of the experts during the standing phase was 16.2 (SD 2166.6) mm/s², and those of the non-experts was 41.1 (SD 3042.9) mm/s² (p = 0.82) (Table 6). The average acceleration of the experts during the rotating phase was -31.7 (SD 2129.9) mm/s², and those of the non-experts was -9.2 (SD 2477.7) mm/s² (p = 0.91). The average acceleration of the experts during the seating phase was 22.1 (SD 2447.9) mm/s², and those of the non-experts was 53.5 (SD 2517.4) mm/s² (p = 0.96).

Table 6. The average acceleration of participants.

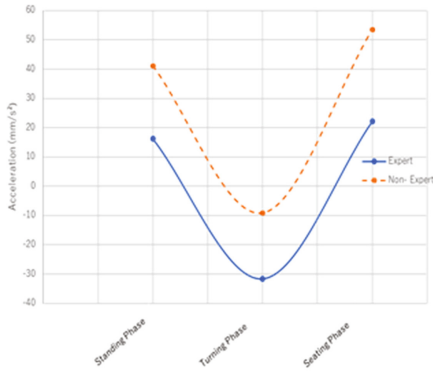
Acceleration (mm/s ²)	Expert N = 2	Non-expert N = 4	p
Standing phase	16.2 (SD 2166.6)	41.1 (SD 3042.9)	0.82
Turning phase	-31.7 (SD 2129.9)	-9.2 (SD 2477.7)	0.91
Seating phase	22.1 (SD 2447.9)	53.5 (SD 2517.4)	0.96

3.5 Comparison of the Average Accelerations of SP During Wheelchair Transfer Between the Experts and the Non-experts

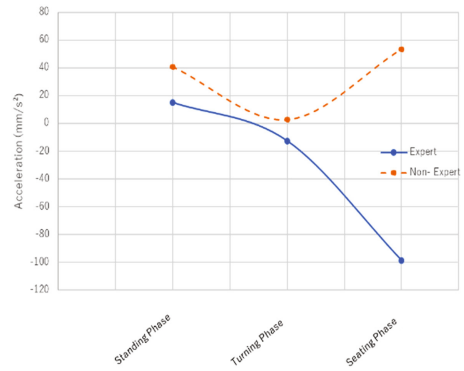
The acceleration mean of SP during the standing phase by the experts was 15.1 (SD 2094.7) mm/s², and the acceleration mean of SP by the non-experts was 40.8 (SD 3034.4) mm/s² (Table 7). The acceleration mean of SP during the rotating phase by the experts was -12.5 (SD 3339.8) mm/s². The decrease in the speed was observed as the experts' cases (Fig. 5). The acceleration mean of SP by non-experts was 2.6 (SD 2293.1) mm/s², and its speed increased (p = 0.53). The acceleration mean of SP during the seating phase by the experts was -98.6 (SD 3137.7) mm/s², and its speed decreased. On the other hand, the average acceleration of SP by non-experts was 53.5 (SD 2517.4) mm/s², and its speed increased (p = 0.54).

Table 7. The average acceleration of the SP.

Acceleration (mm/s^2)	Expert N = 2	Non- expert N = 4	p
Standing phase	15.1 (SD 2094.7)	40.8 (SD 3034.4)	0.84
Turning phase	-12.5 (SD 3339.8)	2.6 (SD 2293.1)	0.53
Seating phase	-98.6 (SD 3137.7)	53.5 (SD 2517.4)	0.54



The Average Acceleration of the Participants.



The Average Acceleration of the SP.

Fig. 5. Comparison of average acceleration of SP during the wheelchair transfer by the experts and the non-experts.

3.6 Comparison of Body Pressure Distribution on the Contact Surface Immediately After Seating on the Wheelchair

The average body pressure of the SP immediately after the experts assisted his seating on the wheelchair was 92.8 (SD 8.4) mmHg, and immediately after seated the non-experts assisted his seating was 108.3 (SD 13.3). The number of the non-experts was higher.

4 Discussion

Following is the discussion on the comparison of the difference between the transfer motion by the experts and the non-experts during the wheelchair transfer through joint angles, transfer time and the distance to the SP, and its influence on the acceleration of the SP.

4.1 Comparison of the Angles of Cervical Spine, Lumber, Knees and Elbow Joints During the Wheelchair Transfer by the Experts and the Non-experts

The experts tended to stretch their necks, lower backs and elbow joints at statistically significantly more than the non-experts, held the body almost straight, and transferred

the SP to the wheelchair while bending their knees. Their spines curved inwardly at the cervical spine and lumbar. The lordosis of the cervical spine part worked as a spring to support their head, and the lordosis of the lumbar part supported the weight of entire upper body, and worked as a fulcrum that gave mobility. Moreover, due to the physiological bowing, the lumbar part evenly distributed the load of the upper body on the interspinous disk surface. [11] From this fact, it is inferred that the experts conducted a transfer movement without apply load on their lumbar. On the other hand, the transfer motion done by the non-experts while they assisting the SP to a wheelchair in forward tilted posture showed smaller flexed angles of knees than those of the experts, and which may have increased the burden on their lower backs.

From the fact that the experts bent elbow joints less than the non-experts, it is inferred that the experts had smaller force moments of the elbow parts, leading to less burden on the arms. On the other hand, the average elbow angle of the non-experts was 95.5° and the upper arms were stretched. Thus, it is inferred that the non-experts were conducting transfer motions that burdened the arms.

4.2 Comparison of the Distance of Head Front During the Wheelchair Transfer by the Expert and the Non-expert

The experts had closer distance of head front to SP at statistically significant level than those of the non-experts. The experts came closer to the SP in order to bend the elbow joints shallower and to control the force moments during the rotating phase.

The non-experts stretched upper arms and bent the elbow joints while holding the SP. It is inferred that the bending of the elbow joints may have lessened the burden on the biceps, the forward bending of the upper body caused burden on the back muscle, which may lead to putting load on the lower backs.

4.3 Comparison of the Average Acceleration of SP During the Wheelchair Transfer by the Expert and the Non-expert

No statistically significant difference was observed when the average acceleration of the SP by the experts and the non-experts was compared. When being assisted by the experts, the SP seemed to accelerate more gently and stood up, in comparison to the cases of the non-experts. During the rotating phase, the experts changed the direction while controlling the motion speed. And during the seating phase, the experts helped the SP seated with gentle acceleration. It is inferred that the experts was controlling speed based on the rules of body mechanics. The experts swayed wider during the reciprocating motion of the rotating phase compared to those of the non-experts, because they moved their heads for checking the seating position on the wheelchair while changing the direction.

On the other hand, the acceleration of the non-experts during the standing phase was 3.9 times larger and faster than those of the experts. It is inferred that, because the non-experts was shortening the distance by pulling the SP closer with forward bending posture during the rotating phase, the negative acceleration was smaller than those of the experts. The acceleration during the seating phase of the non-experts was four times larger than those of the experts. It seemed that they couldn't adjust speed, which resulted

in slightly faster in the seating time. It is inferred that the downward acceleration occurred at the beginning of the seating motion was large, and the stretching muscles moment of the hip joint and the knee joints of the SP did not fully function. Thus the downward acceleration was not suppressed, and the hip of the SP touched the seat surface with faster speed. This series of motions resulted in the higher body pressure.

Furthermore, the experts required longer average time for the wheelchair transfer than the non-experts. This is inferred that the experts evaluated the physical function and motion of the SP and adjusted the speed accordingly. It was suggested that this speed adjustment was one of nursing skill to reduce the body pressure immediately after seating and to offer more comfortable seating according to the SP's pace. The range of this study was the fact that we had small number of participants and therefore the results could not be generalized. We feel the strong necessity to continue further motion analyses.

5 Conclusion

Compared to the non-experts, the experts significantly stretched the cervical spines and the lumbers, held their bodies almost straight, and conducted the transfer motion that caused less load on the cervical spine, the lumber, the knee joints and the elbow joints. The non-experts conducted the transfer motion with forward bending posture, which brought burden on the lumber. There was no statistically significant difference in the influence on the acceleration of the SP between the wheelchair transfer motions of the experts and the non-experts. The experts accelerated gently, held the standing position, turned while adjusting acceleration and assisted the SP seated smoothly. As the experts gained the skill to control speed, knowledge and logical thinking through experience, quantification of the acceleration will be useful for the training of the non-experts.

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