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Evaluation Parameters for Care-Giving Motions

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Abstract. Quantitative evaluation parameters for care-giving motions were investigated by analyzing three-dimensional motion data of skilled and unskilled caregivers. Subjects were three skilled caregivers, each of whom had over 12 yrs of clinical experience, and four physical therapy students. We recorded a typical care-giving motion between a caregiver and a care-receiver three times for each caregiver/receiver pair with a 3-D motion analysis system (VICON system, Oxford Metrics, UK). We did time-series analyses to extract performance evaluation parameters from observed indexes such as trajectories, velocities, accelerations of the body's center of gravity (COG), jerk-cost, and impulse. The analyzed motion was lifting a patient lying on a bed into the sitting position. The skilled caregivers' operation times were shorter than those of the unskilled caregivers. The COG trajectories of skilled caregivers showed smoother and better reproducibility over the three trials, and the COG velocity curves showed a high single peak at start up. The jerk-cost and impulse of skilled caregivers were lower than those of unskilled caregivers. We found reproducibility and smoothness of movement to be good evaluation parameters for care-giving motions. The measurement indexes observed in this study should be introduced to improve evaluation of the education of unskilled caregivers.
Key words: Characteristics of the skilled caregiver, 3D motion analysis, Jerk-cost

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INTRODUCTION

Skilled movements, which can be acquired through training and practice, help achieve certain objectives associated with a particular task. It has been demonstrated in several studies[1, 2)] that skilled movements are characteristically smooth. Smoothness of movement has been quantified[1–4)] using the mean squared magnitude of jerk, where jerk is defined as the third order derivative of position. In mathematical terms, to produce the smoothest possible movement, the criterion function, jerk-cost (JC), is defined as

$$JC = \int_0^T \left| \frac{d^3 r}{dt^3} \right|^2 dt, \qquad [1]$$

where T is movement duration and r denotes the position vector.

The original model of maximum smoothness (minimum jerk) was derived for a voluntary human arm movement. When moving a hand between a pair of targets, subjects tend to generate a straight path with single peak, bell-shaped velocity profiles.

Hogan[3)] suggested that the meaning of this trajectory is that the minimization of mean-squared jerk is a mathematical model of one movement objective, the production of smooth, graceful movements. This model is called the minimum jerk model. The model has been used successfully to simulate single-joint planar movement[3, 5, 6], and multi-joint movement[7]. The model has also been used to evaluate motor performance during skill acquisition. Schneider and Zernicke[8] showed that significantly less JC was observed in the slowest hand movements after subjects had practiced the movements. Hreljac[9–11] argued that smoothness of gait can be quantified by evaluating JC and that competitive runners tend to exhibit smoother strides than recreational runners during both running and fast walking. Also, examination of development of reaching movements among human infants showed increasingly rapid decrease of movement jerk with increasing age[12–14].

In Japan, development of human resources is an issue that has become increasingly urgent as the population ages. However, skill parameters as a basis on which to decide how much care-giving motion training should be done have not yet been established. It is generally agreed that the motions of skilled caregivers are typically smooth, and it is hypothesized that the minimum-jerk model applies to care-giving motions. One important difference between care-giving motions and casual movements is that care-giving motions are derived from the interaction of the caregiver and care-receiver, which requires the safety and comfort of both parties.

The purposes of this study were to examine whether JC was an appropriate skill parameter for care-giving motions and to investigate other quantitative evaluation parameters for care-giving motions. In order to investigate the kinetic characteristics of skilled caregivers during the interactive movements of caregiver and care-receiver, we analyzed three-dimensional motion data for skilled and unskilled caregivers.

METHODS

The care-giving subjects were three skilled and four unskilled caregivers. The skilled caregivers were women who each had 12 years or more of experience as a physical or occupational therapist. They were between 153 and 160 cm tall and weighed between 50 and 56 kg. The unskilled subjects were female students in the second year of a physical therapy training course who were

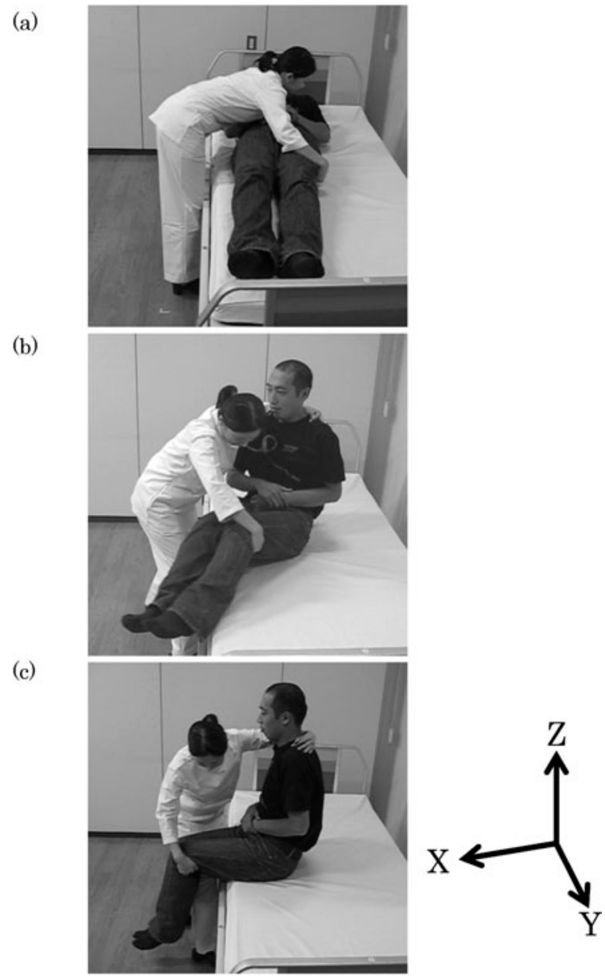

Fig. 1. Care-giving body movement.

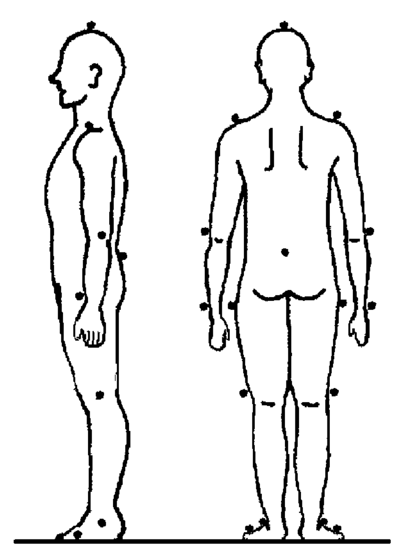

Fig. 2. Marker locations on the body.

Table 1. Comparison of the results in the skilled and unskilled caregivers

	Skilled caregiver	Unskilled caregiver
Operation time	2.86 ± 0.40 (s)	5.03 ± 0.69 (s)
COG trajectory		
Correlation coefficient among three trials per subject	X: 0.988 ± 0.007 Y: 0.960 ± 0.029 Z: 0.952 ± 0.021	X: 0.896 ± 0.066 Y: 0.869 ± 0.057 Z: 0.890 ± 0.084
Total length of the COG trajectories	caregiver: 542 ± 31.8 (mm) client: 505 ± 34.2 (mm)	caregiver: 655 ± 53.9 (mm) client: 643 ± 52.8 (mm)
correlation coefficient between caregiver and client	X: 0.955 ± 0.021 Y: 0.916 ± 0.030 Z: 0.900 ± 0.065	X: 0.944 ± 0.040 Y: 0.901 ± 0.045 Z: 0.954 ± 0.021
Jerk-cost per second	$(5.05 \pm 1.21) \times 10^{11}$ $[(mm/s^3)^2/s]$	$(10.9 \pm 6.36) \times 10^{11}$ $[(mm/s^3)^2/s]$
Impulse	$(58.6 \pm 8.02) \times 10^3$ (N·s)	$(84.5·13.0) \times 10^3$ (N·s)

between 155 and 162 cm tall and weighed between 44 and 60 kg. The students were taking a course in care methods and practiced care procedures several times a year with other students. The care-receiving subject was a male in his 20 s, who was 172 cm tall and weighed 69 kg. The care-receiving subject was requested to relax the muscles throughout his body during the experiment.

The analyzed motion was lifting a patient from the prone position on a bed into the sitting position. This motion is a basic and typical care giving motion and requires the caregiver to support the body weight of a care-receiver safely and comfortably during the movement. As shown in Fig. 1, the care-giving subjects were positioned on the right side of the care-receiving subject on the bed (Fig. 1(a)), and the caregiver performed the entire motion of raising (Fig. 1(b)) and seating the care-receiving subject on the side of the bed (Fig. 1(c)).

After two practice trials, the subjects performed the motion for measurement three times.

The apparatus used to measure body movement was a three-dimensional motion analysis system with six cameras (VICON512 motion capture system, Oxford Metrics Inc.). The frame rate was 120 Hz. Sixteen reflective markers were attached over specific body landmarks (Fig. 2). Markers were fixed on parts of the care-giving and care-receiving subjects' bodies. The starting point of the motion was determined using a ground reaction meter.

The body's center of gravity was approximated using a rigid link model, consisting of 11 segments: two each for the bilateral upper arms, forearms, femurs, cruses, foot regions and the head and trunk. Each segment was determined based on the above 16 marker points.

Based on the data of the marker position and the position of the center of gravity within each segment, the body's center of gravity in the care-giving and care-receiving subjects was determined by calculating the weighted mean of the centers of gravity in the segments. Although data for all marker positions were required to determine the body's center of gravity, when a marker was behind the body (in relation to the apparatus), the body's center of gravity was determined by spline interpolation using the positions of the near markers.

The time when the ground reaction of the care-giving subject changed was defined as the starting point, and the time when the movement of the body's center of gravity in the care-receiver was stopped was defined as the completion point. The trajectory of the body's center of gravity in the care-giving and care-receiving subjects was analyzed as follows:

(1) Correlation of the trajectory of the body's center of gravity in a single caregiver between the three trials.

(2) Correlation between the trajectories of the body's center of gravity in the care-giving and care-receiving subjects.

(3) Total length of the trajectory of the body's center of gravity (m).

$$\sum_{i=1}^{n}\sqrt{(x_{i+1}-x_i)^2+(y_{i+1}-y_i)^2+(z_{i+1}-z_i)^2} \qquad [2]$$

Here, xi, yi, and zi denote the x, y, and z coordinates, respectively, at a point in time i, and n denotes the total number of data.

The correlation coefficient was determined on each coordinate axis by pair comparison of the trajectory in the care-giving subject's body's center of gravity during each trial for (1), and by comparison of the care-giving and care-receiving subjects for (2). The movement velocity and acceleration of the body's center of gravity were determined on three-dimensional coordinates, and characteristics of each trial were examined. The movement velocity of the body's center of gravity was calculated by differentiating its position vector, and the acceleration of the body's center of gravity was determined by differentiating the movement velocity. The jerk (J) of the body's center of gravity was determined, Jerk-cost (JC) was calculated as the time integral of J, and the JC per unit time was determined by dividing JC by each operation time. Velocity, acceleration, and jerk data were smoothed using a fourth order, zero lag Butterworth filter after taking the first, second, and third derivations of the position data, respectively. To determine the kinetic momentum, impulse (I) was calculated by multiplying the value obtained by the time integral of the acceleration curve of the care-receiver from starting time to completion time during each trial by the body weight of the care-receiver. It was assumed that the care-receiver was relaxed.

$$JC = \int_0^T \left| a \right| \times m dt \qquad [3]$$

Here, *a* denotes acceleration, and *m* denotes the body weight of the care-receiver.

RESULTS

The operation time required for body movement was about 3 sec for the skilled caregivers and about 5 sec for the unskilled caregivers (Table 1). The difference in mean operation time between the two groups using the Welch t test was significant (p<0.05).

Figure 3 shows typical trajectories of the body's COG of skilled and unskilled caregivers in the X-Y (horizontal) plane. Good reproducibility was observed among the skilled caregivers (Fig. 3(a)) but was barely observed among the unskilled caregivers (Fig. 3(b)). The correlation of the movements among the three trials showed the same results (Table 1). The mean total lengths of the trajectory of the body's COG of the caregivers and care-receiver were significantly shorter for the skilled caregivers than for the unskilled caregivers (p<0.05) (Table 1).

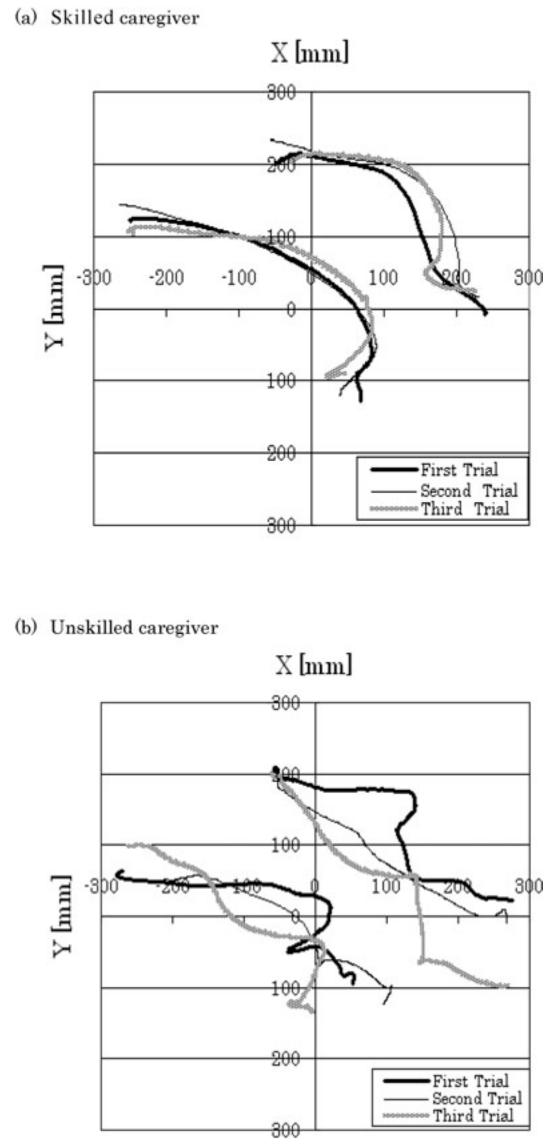

Fig. 3. Trajectories of body's center of gravity in caregivers and care-receivers in the X-Y plane.

Figures 4(a)–(c) show the trajectories of the body's COG of the three skilled caregivers and the care-receiver during the first trial, and Figs. 5(a)–(d)

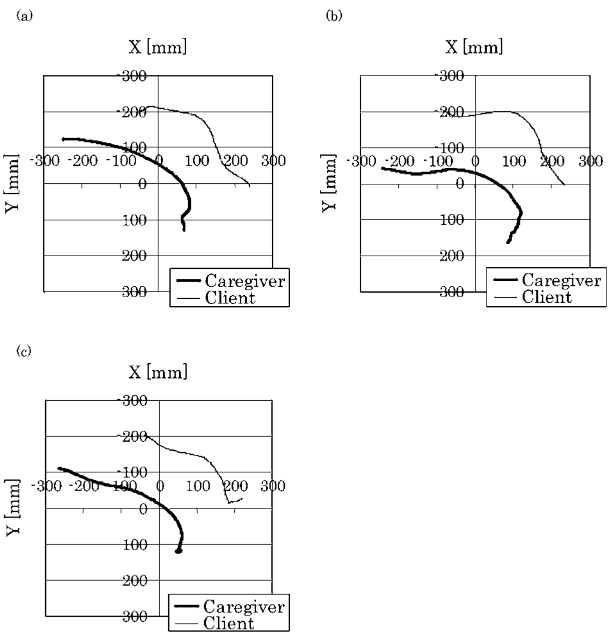

Fig. 4. Trajectories of body's center of gravity in skilled caregivers and care-receivers in the X-Y plane.

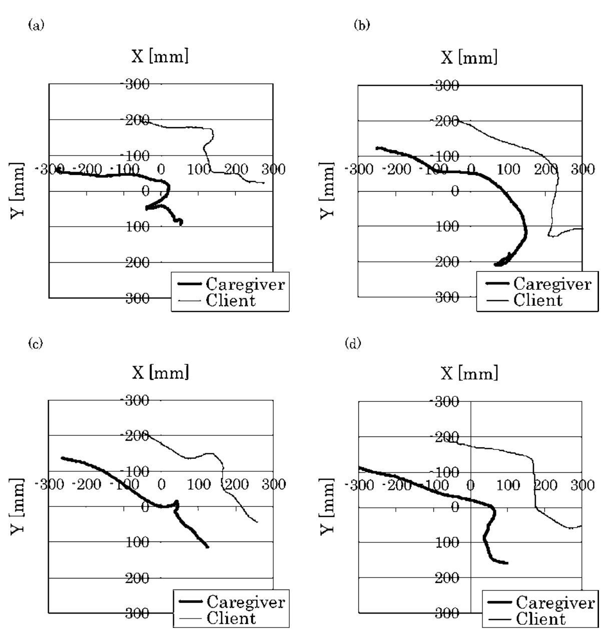

Fig. 5. Trajectories of body's center of gravity in unskilled caregivers and care-receivers in the X-Y plane.

show those of the four unskilled caregivers and the care-receiver during the first trial. The trajectories of the three skilled caregivers showed smooth curves, while the trajectory shapes of the unskilled caregivers were markedly varied. The correlation coefficients of the trajectories of the body's COG between the caregiver and care-receiver were high among all pairs (Table 1).

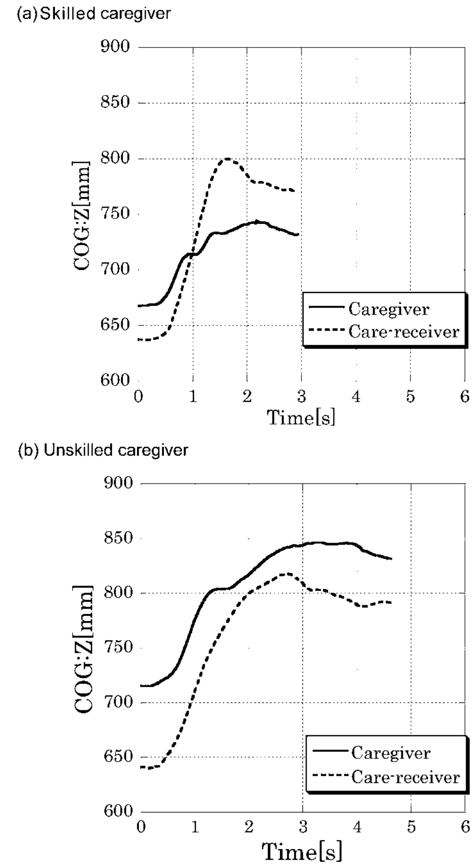

Fig. 6. Trajectories of body's center of gravity in the caregivers and the care-receivers in the direction of the vertical axis.

Figure 6 shows typical trajectories of the body's COG in the Z-axis direction (vertical direction). As shown in Fig. 6(a), the perpendicular movement of the body's COG of the skilled caregivers was 76–97 mm, and the position of the body's COG of the caregivers was lower than that of the care-receiver after a certain care-giving point in time. Perpendicular movement was also greater (132–220 mm) for the unskilled caregivers (Fig. 6(b)) than for the skilled, and the unskilled caregivers' bodies' COGs were always higher than that of the care-receiver.

In the motions of skilled caregivers (Fig. 7(a)), the velocity of the motion increased rapidly and then decreased rapidly. The mean of the highest velocity of the three skilled caregivers was 0.40–0.48 m/sec. For the unskilled caregivers (Fig. 7(b)), the mean

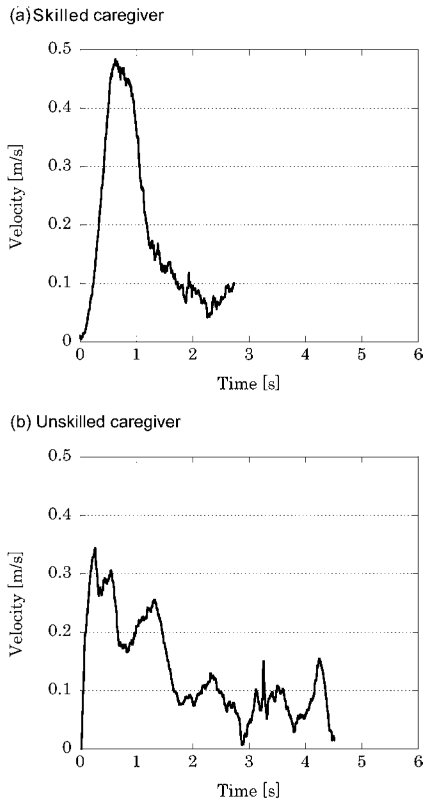

Fig. 7. Velocity of body's center of gravity in caregivers.

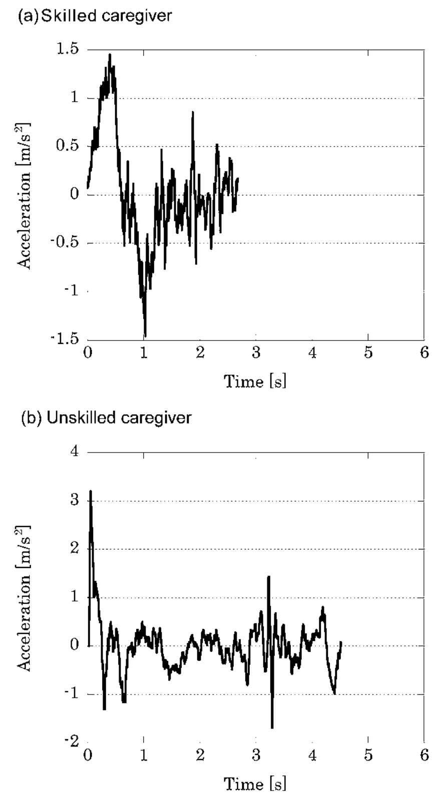

Fig. 8. Acceleration of body's center of gravity in caregivers.

highest velocity was lower (0.22–0.32 m/sec).

Figure 8 shows the acceleration of the body's COG in the caregivers. For the skilled caregivers (Fig. 8(a)), acceleration increased soon after the start of motion and showed a single peak. For the unskilled caregivers (Fig. 8(b)), the highest acceleration was lower than that of the skilled, and acceleration and deceleration alternated irregularly.

The jerk-cost per unit time was lower for the skilled caregivers than for the unskilled caregivers (Table1), and the difference in the mean jerk-cost was significant ($p<0.05$).

Impulse in all trials was lower for the skilled caregivers than for the unskilled caregivers (Table 1), and the difference was significant ($p<0.05$).

DISCUSSION

In this study, we demonstrated that there are significant differences between the smoothness of trajectories of the body's COG of skilled and unskilled caregivers, and the JC of movement of skilled caregivers' was less than that of unskilled caregivers' (Table 1). The skilled caregivers' motions also showed a bell-shaped velocity curve.

Moreover, the movements of skilled caregivers were highly reproducible and stable. This result suggests that trajectories of skilled caregivers were produced from movements based on the same model. If we take these results into consideration, it is reasonable to suppose that JC is applicable as a parameter for the care giving motion.

We also analyzed the movements of the caregiver and the care-receiver in parallel. The trajectories of the caregivers' bodies' COGs were similar to those of the care-receiver's, and the correlation coefficients of the trajectories between the caregiver and care-receiver were high for both skilled and unskilled caregivers (Table 1). Therefore, the JC to the care-receiver when assisted by a skilled caregiver was less than when assisted by an unskilled caregiver. Since jerk is the rate of change in acceleration, the unskilled caregivers may frequently have accelerated and decelerated movement of the care-receiver's body. A smooth trajectory of the body's COG during the care-

Table 2. Characteristics of movement in skilled caregivers

1. Smooth trajectory of the body's COG
2. High velocity in the initial stage and single peak of acceleration
3. Effective use of elements of force, such as inertia
4. Minimization of energy required for care-giving motions by reducing impulse and total movement of the body's COG
5. Lower position of COG in the caregiver than in the care-receiver means reduction of stress on the lumbar and other vulnerable regions

receiving period is considered important to the comfort of the care-receiver, suggesting that this should be a parameter for appropriate care-giving motions.

Kjellberg[15] argued that the quality of work techniques used in the health care sector were positively correlated with the patients' perception of safety and comfort. Our study's results support his conclusion.

Other differences were found in the characteristic motions of skilled and unskilled caregivers. There were significant differences in operation time, total length of the trajectory of the body's COG, and impulse between skilled and unskilled caregivers (Table 1). The rapid completion of the care-giving motion by skilled caregivers was due to the high velocity of the initial motion, which also reduced impulse and kinetic momentum. Observation of the care-giving motions of the skilled caregivers suggested that the force of inertia was effectively used by quickly accelerating the motion of the care-receiver's body in the initial stage of movement.

The perpendicular movement of the skilled caregivers' bodies' COGs was smaller than that of the unskilled caregivers' bodies. The positions of the skilled caregivers' bodies' COGs were lower than that of the care-receiver's body's COG, but for the unskilled caregivers, they were generally higher than the care-receiver's. The skilled caregivers reduced movement of the body's COG against gravity, and suppressed anterior bending of the trunk of the body by positioning their bodies' COGs lower than that of the care-receiver's body, leading to a motion that did not increase lumbar stress.

Based on these findings, the characteristics of movement in skilled caregivers were as follows: smooth trajectory of the body's COG, high velocity in the initial stage and single peak of acceleration, effective use of elements of force such as inertia, minimization of energy by reducing impulse and total movement of the body's COG, and lower position of COG in the caregiver than in the care-receiver (Table 2).

In conventional caregiver training courses, trainees practice and repeat care-giving techniques until they become expert in the techniques. However, handling of patients causes a lot of physical stress in caregivers, often resulting in musculoskeletal disorders[16–19]. Inexpert care techniques have been reported as a cause of such disorders[20]. To help trainees acquire skills, it is important to not use repeated exercises as the only guide. Application of parameters of skill in care-giving motions is also important. The problem of how to apply these parameters in the training course should be examined in follow-up studies.

In this study, there were a limited number of subjects, and evaluation was limited to a single care-giving motion. We will re-examine the parameters used in this study by quantifiably evaluating various care-giving motions with a larger number of subjects and establishing criteria for learning care-giving motions and efficient methods of training in care-giving motions.

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