Washer-dryer for Every Person: Ergonomics and Biomechanical Interventions

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***Abstract*—Recently, "Washer-Dryer" type of washing machines with horizontal or slant drum are becoming popular in Japan. We have measured and analyzed the posture while using the machines with the 3 dimensional motion capture measurement device. Subjective usability questionnaire were also used. After the measurement, measured working postures are analyzed with the human kinematics model (3D SSPP) that can estimate theoretical value of the muscle tension and loads on the lumber vertebrae, knees and ankles. Three types of washers (European type; box shape and horizontal drum, Conventional Japanese type; a vertical drum, New type; slant drum with higher profile) were used for the experiment.**

The new type requires only 40% of the muscular force than conventional Japanese type.

From the subjective evaluation, the new type was better than the European type washer and conventional type on two of the question, subjective fatigue and general evaluation, with statistical significance. Finally, comparison between elder and younger subjects was done.

I. Introduction

RERENTLY, "Washer Dryer" type of washing machines with horizontal or slant drum is becoming popular in Japan. Traditionally, Japanese washing machines have had vertical drums and these types are still popular. Users of vertical drum washer have to bend their back and stretch their arm to put in and take out laundry. Meanwhile in Europe, horizontal drum type washing machines have always been popular. This type requires the crouching posture for putting in and taking out laundry because of its lower height.

The "washer-dryer" type washing machines have rather different mechanisms to the vertical drum washing machines, and therefore require a completely new mechanical design. These new washer-dryers have horizontal or slanted rotational axis of the drum. Thus, the shape of the washing machine was greatly changed; to make loading operations easier, the door position was modified.

In this research, physical loads and usability between the washer-dryer, the traditional drum type and European type washing machines were compared. This comparison was performed using subjective evaluations, 3D motion capture and estimation of body part loads using a human kinetics computer model.

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II. Method of the Evaluation Experiment

In the experiment, we requested the participants to take out laundry from the machine. As a laundry model, two towels were placed at the bottom of the drum, and two blankets (each 1.6 kg) were placed on the towels. These items were dry.

The participants were asked to open the door, take out the laundry piece by piece, put them into a basket that was placed on the floor, and then close the door.

The participants were 12 females aged 20s to 40s. Four subjects were smaller height (148 to 153cm), 5 subjects were around 158cm (Japanese female average) and 3 taller subjects were around 165cm.

Three laundry machines were used: a European floor-type box-shaped washing machine (SANYO AWD-500; referred to below as "EU type"), a typical vertical-drum washing machine (SANYO ASW-800; referred to as "vertical drum"), and a slanted-drum fully-automatic washer-dryer machine (SANYO AQ-1; referred to as "slanted drum"). Height to the center of the opening was 47.5 cm for the EU-type machine, 90 cm for the vertical-drum machine, and 81 cm for the slanted-drum machine. Note that the opening of the vertical-drum machine faces straight up, which means that laundry will have to be lifted higher than the actual height of the door.

Fig.1. Washers and a New Washer-Dryer; European (EU) type AWD-500, Vertical Drum type ASW-800 and Slanted Drum type washer-dryer AQ-1(Left to Right).

III. Results of Subjective Evaluation

Subjective evaluation was carried out by asking the participants a set of questions each time the required task was completed. Of these questions, 5 were related to fatigue, 5 on usability and a final question on the general usability of the washing machine. Table 1 lists the questions asked. Each question was answered on a 5-level basis.

Table 1 Questions for Subjective Evaluation

1. How tired does your entire body feel?
2. How tired are your neck or shoulders?
3. How tired are your upper arms?
4. How tired are your back?
5. How tired are your knees?
6. How easy was it to pushing the door open button?
7. How easy was the machine to opening and closing the door?
8. How easy was the machine to checking inside the drum?
9. How easy was the machine to inserting a hand or arm inside the drum?
10. How easy was the machine to taking out laundry?
11. How easy was the machine to use?

We used one-way analysis of variance to investigate whether differences in the evaluations from one machine to another were significant. We found that differences between machine types for the question "How tired does your entire body feel?" were indeed significant ($F(2,33)=11.68$, p=0.0001) and that the evaluations rated the slanted-drum machine as best followed by the vertical-drum machine and the EU-type machine.

For post-hoc pair-wise comparison, we used Tukey-Kramer Honestly Significantly Different (HSD) test, it was found that the slanted-drum machine and vertical-drum machine were evaluated significantly better than the EU-type machine ($p<0.05$).

There are significant differences between washing machines on following questions; "How tired are your neck or shoulders?" ($F(2,33)=9.85$, p=0.0004), "How easy was the machine to use?" ($F(2,33)=22.30$, $p<0.0001$), "How easy was it to opening and closing the door?" ($F(2,33)=7.98$, $p=0.0015$), and "How easy was the machine to checking inside the drum?" ($F(2,33)=9.48$, p=0.0006). Similarly, a HSD test revealed that the slanted-drum machine and vertical-drum machine were evaluated significantly better than the EU-type machine ($p<0.05$).

There were also differences between the machines for "How easy was the machine to taking out laundry?" ($F(2,33)=7.98$, $p=0.0015$). For this question, the machines were highly evaluated in order of slanted drum, EU type, and vertical drum, and a HSD test revealed a significant difference between the slanted-drum and vertical-drum machines ($p<0.05$).

The question "How easy was the machine to pushing the door open button?" applied only to the slanted-drum and EU-type machines that have door buttons, and it was found that the former was evaluated significantly higher than the latter ($F(1,19)=14.31$, $p=0.001$).

The above results indicate that the slanted-drum machine was evaluated higher for all questions and that the EU-type machine was inferior in a statistically significant manner in terms of fatigue and ease of use. It was also found that the vertical-drum machine, which has been widely used in Japan until recently, was not very good for taking laundry out from the drum. We will investigate the relationship between these results and working posture as determined by motion capture described next.

IV. Measurement of Working Postures by Motion Capture and Analysis of Joint Angle

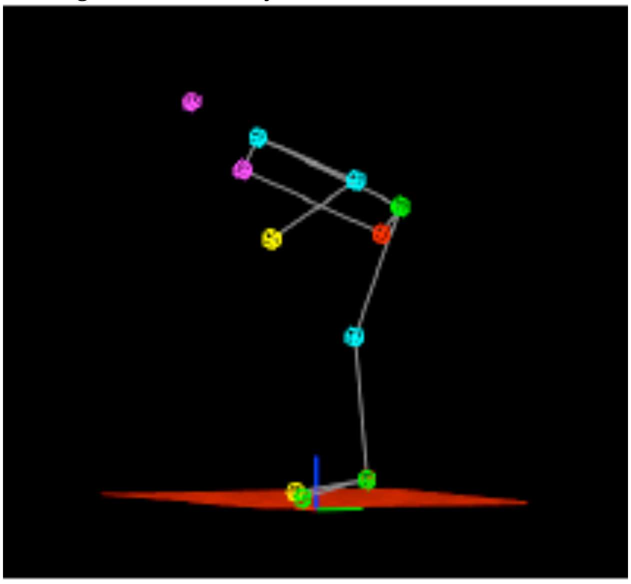
We have measured working postures with 3D motion capture system. The system was Proreflex system (Qualisys Inc., Sweden) which has 5 IR cameras. Using a 3D motion-capture system employing infrared cameras, we measured working posture in terms of coordinate values for various parts of the body. Sampling rate was set at 120 samples/s and spatial resolution setting during measurements was 5 – 10 mm. Figure 2 shows the posture of a subject with a height of 158 cm (the average for Japanese women) during maximum bending of the body when removing a towel from the drum.

Markers were set at 15 locations on the subject's body: head, left and right shoulders, left and right elbows, back (dorsal) of each hand, left and right greater trochanter, left and right knees, left and right ankles, and left and right toes (on the subject's slippers).

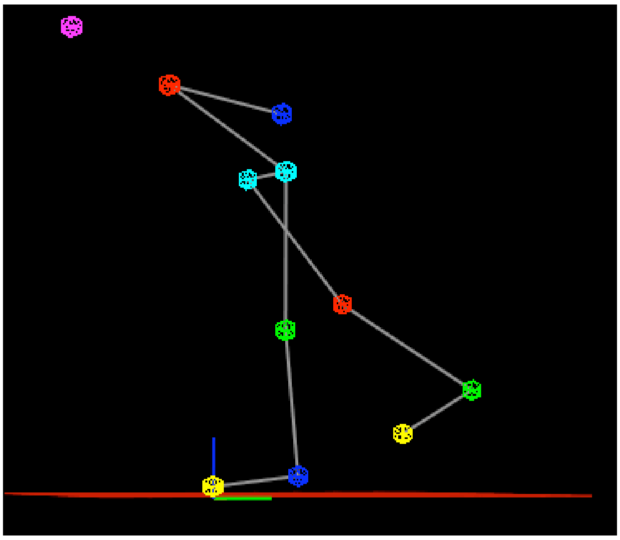
Using data from motion capture, we measured and analyzed the angle formed by the knee, greater-trochanter and shoulder. This angle was 100 degrees (averaged between subjects) for the slanted drum, 114 degrees for the vertical drum, and 64 degrees for the EU type (Fig. 3). Since standing posture is near to 180 degree, the larger angle is better.

One-way analysis of variance indicated that differences between machines were significant ($F(2,33)=37.622$, $p<0.0001$). Results of a HSD test revealed a significant difference between the slanted-drum and EU-type machines and between the vertical-drum and EU-type machines ($p<0.05$).

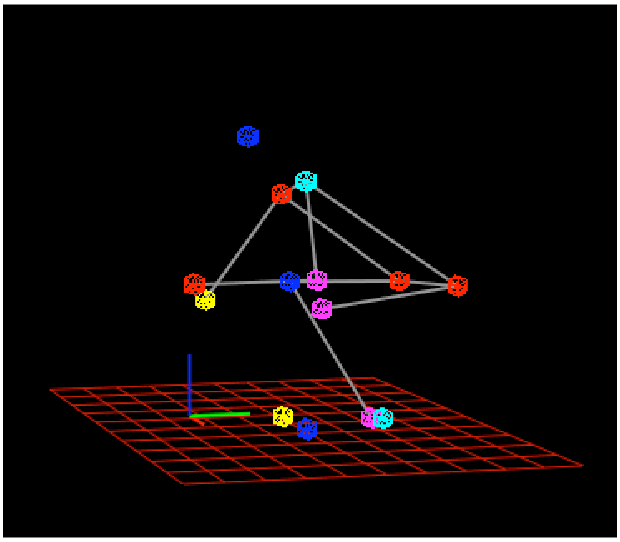
The angle formed for the slanted drum was 110/64=1.71 times larger than that of the EU type, which can be interpreted as a 70% improvement. For the EU type, the capture screen showed that laundry could not be put in or taken out without squatting completely. This is the reason for the poor evaluations given to the EU-type washing machine for the questions "How tired does your entire body feel?", "How tired are your knees?", and "How easy was the machine to use?" The vertical drum gave a posture closer to the vertical stance than that of the slanted drum, but since the vertical drum is deep, almost all of the participants reach the towel at the bottom of the drum without raising one foot off the ground and stretching inside the drum. This is why the vertical drum was poorly evaluated with respect to "How easy was the machine to taking out laundry?" The relationship between the subjective evaluation and working posture has therefore been clarified by measuring body posture through motion capture and calculating the angle of body bending in the above way.



Slanted drum



Vertical drum



EU type

Figure 2: Posture during maximum bending of body (158cm young female)

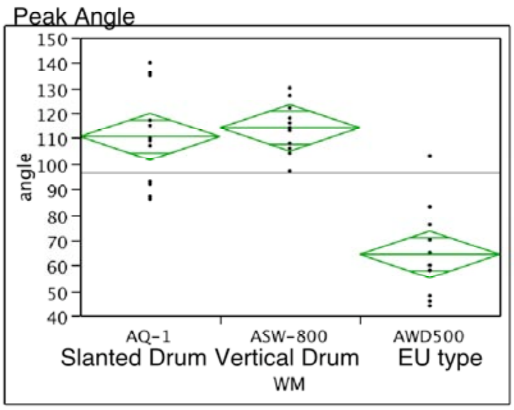


Figure3:Angles formed by the knee, greater-trochanter and shoulder for different machines

It has been shown that the vertical drum requires an off-balanced posture. The entire body load at this time cannot be estimate solely on the basis of coordinate and angle data obtained through motion capture. The load on the lumber vertebra that cannot be directly measured is also a decisive factor. Accordingly, giving due consideration to the mass of various parts of the body, we attempted to estimate such loads using a kinematic model.

V. Estimation of Static Load using a Kinematic Model

We have estimated the load on various parts of the body using a kinematic model. To perform our calculations, we used the 3D Static Strength Prediction Program (3D SSPP) developed by a research team lead by Professor Don Chaffin at the University of Michigan. Professor Chaffin has been researching kinematic models of the human body and applying them to posture analysis of assembly of production lines for about 30 years.

As shown in Fig. 4, the Chaffin model features a human body with a basic structure consisting of 7 links. Links are; forearm, upper arm, torso (shoulder to lumbar vertebra), sacral vertebra to pelvis, femoral head to knee, shank and foot.

The model takes the following values as main parameters; load, own weight, height and joint coordinates. Center of gravity is determined by each part's size and weight. For the example, a load of 5 kg (49N) is held in the hand with the combined weight of the forearm and hand is 15.8N (Fig.5).

The upper arm from the elbow up holds up this load with force R_{elbow} in a stationary position. This can be expressed as -49N-15.8N+R_{elbow}=0, which means that R_{elbow} can be calculated to be 64.8N in the upward direction.

Rotation moment M_E is in equilibrium with the (center of gravity of the upper arm X the weight of the upper arm and hand) + (length from the joint to the grip X the load). This can be expressed as 17.2cm(-15.8N) + 35.5cm(-49N) + M_E=0.

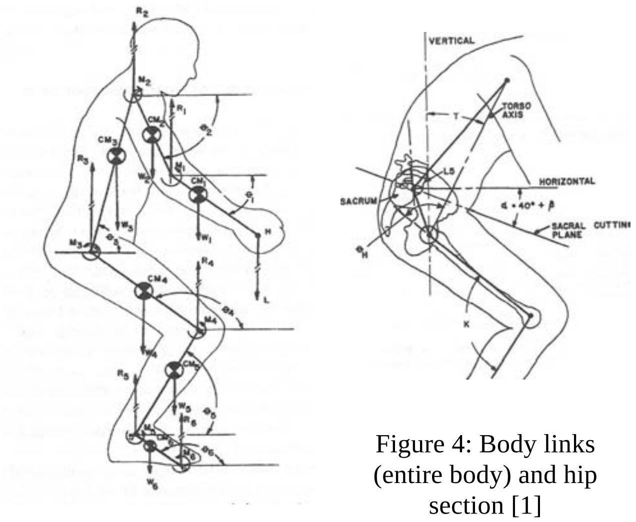


Figure 4: Body links (entire body) and hip section [1]

This gives M_E=2011.3Ncm (20.113Nm). This assumes the forearm to be in a horizontal position, so any deviation from the horizontal in the form of -q_E will give a result of $\cos\theta_E(M_E)$.

For the upper arm, the upward pulling force at the shoulder can be expressed as $R_S=W_{UA}+R_{elbow}$, where W_{UA} is the upper arm's own weight. The torque at the shoulder can be expressed as $M_S = -(SCM_{UA})(W_{UA}) -(SE)(R_{elbow}) -(M_E)$, where SCM_{UA} is the distance from the shoulder to the center of gravity of the upper arm, and SE is the length of the upper arm.

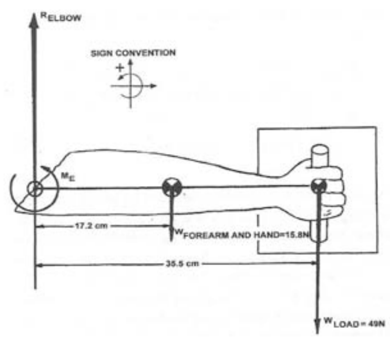


Figure 5: Forearm and load (from Ref. [1])

Lowering the upper arm from the horizontal gives a result of $\cos\theta\,(M_S)$. In the above way, load and joint moments can be progressively calculated for various parts of the body (Fig. 6).

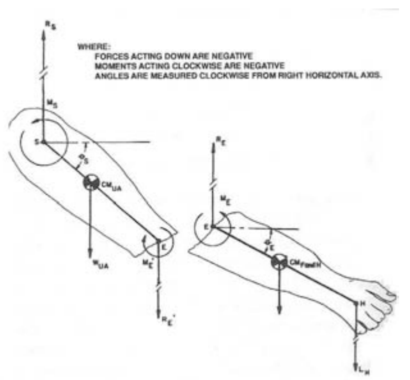


Figure 6: Upper arm and forearm (from Ref. [1])

Using this model, we estimated the pressure (N) on the disk between the fourth and fifth lumbar vertebra and the maximal voluntary contraction (%MVC) for the muscles involved in the elbow, hip, knee, and ankle joints for the posture corresponding to maximum bending of the body (for a 158-cm, 53-kg participants). Participants' height and weight were used for estimation. Referring to Table 2 and Fig. 6, the slanted drum exhibited smaller muscle strengths except for the hips. For the vertical drum, the pressure on the inter vertebrae disk was smaller than that of the other two machines since the back was not bent very much. On the other hand, laundry cannot be removed from the bottom of a vertical drum without raising one foot so that the load on the ankle of the other foot exceeded 100%. The load on the hip and knee was likewise high. Summing up individual %MVCs and comparing overall %MVC between the different machines revealed that the slanted drum was smallest with a muscle load about 60% smaller than that of the vertical drum. On comparing the slanted drum and the EU type, it was found that the latter exhibited a smaller load on the hip but 2.36 times the load on the knee due to the fact that a squatting posture must be taken. The above results demonstrate that the slanted drum provides improved posture.

Table 2: Values estimated by model (158cm young female)

Subject: 158cm/53kg	L4/L5 Comp	%MVC(50 %ile) elbow	hip	Knee	Ankle
Slanted drum	1732	12	54	25	25
EU type	1801	17	31	59	26
Vertical drum	1431	8	75	91	110

	Sum (%MVC)	Sum(%MVC) / 400
Slanted drum	116	0.29
EU type	133	0.3325
Vertical drum	284	0.71

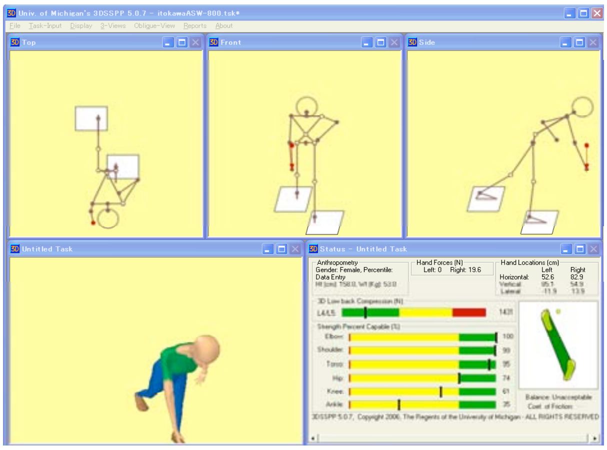


Figure 7: Calculation screen for vertical drum (158cm young female)

VI. Consideration of Height with Body Size Data

In the following, we investigate how different heights for the washing-machine drum affect loads on the body. We compare, in particular, a type-1 slanted drum (AQ-1 : medium drum height) and type-2 slanted drum (low drum height).

For type 1, the distance from the floor to the drum's center height and to the bottom of the drum is about is 85 cm and 55 cm, respectively. For type 2, the distance from the floor to the drum's center height is about 13 cm lower than that of type 1.

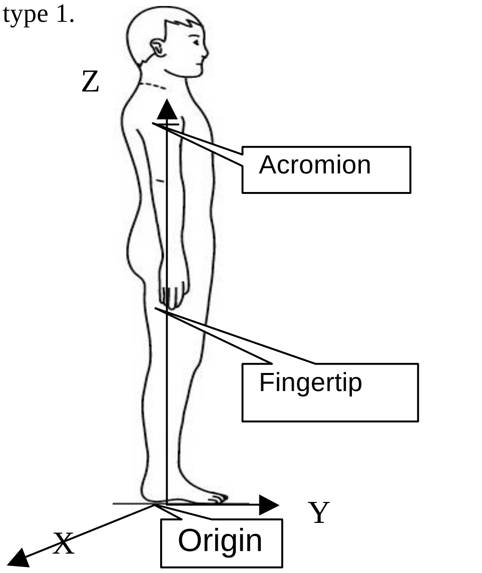


Figure 8: Japanese Body Size Database (from [2])

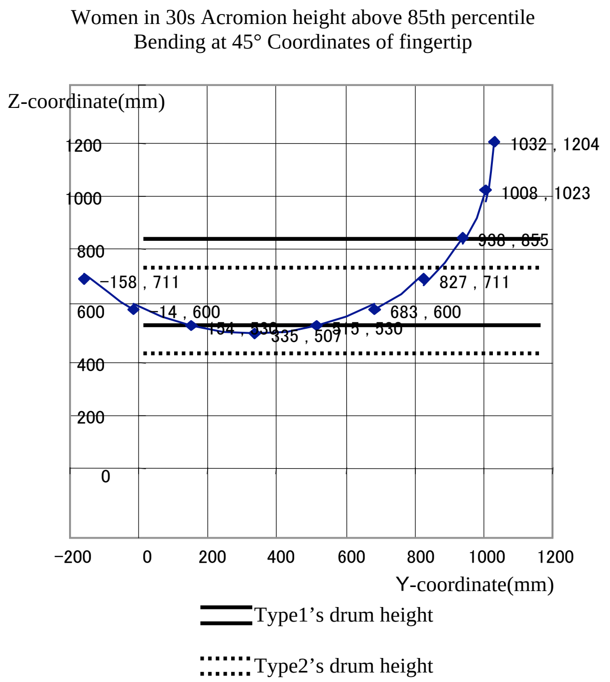


Figure 9: the range of hand reach

Based on the above motion capture data, we simulated total muscle load applied to the elbow, hip, knee, and ankle for both types 1 and 2 and found that total muscle load generated by type-1 slanted drum is about 37% less than that of type-2 slanted drum. Figure 8 shows data obtained with reference to the Japanese Body Size Database (Fig. 9) of the Research Institute of Human Engineering for Quality Life[2].

This figure shows the range of hand reach when bending over at a 45-degree angle for women in their 30s with an acromion height above the 85th percentile. These results show that particularly tall women cannot reach the bottom of the drum in a type-2 machine, which is considered to be one factor affecting body load when removing laundry. In short, body size and range of reach should be sufficiently considered when designing the mechanism of a washer-dryer machine.

VII. Evaluation with Elder Adult

Finally, we have evaluated washers with an elder adult subject. She is 61 years old and is working actively on daily basis. Her height is 151 cm, weight is 50 kg and right-handed.

The most visible difference of posture between young subjects and elder is of balancing strategy.

On vertical drum washer (ASW-800), she grabbed the upper edge of the washer tank with her left hand to keep her bent body. By this strategy, estimated body centroid locates inside of foot area (Fig.10). Younger subjects tend to raise a lower limb to bank trunk and reach their hand to the drum bottom. It is seems that young subjects' strategy which raising a lower limb contributes to avoid bending trunk (compare with Fig.2 vertical drum).

On EU type washer (AWD-500), she completely got down on her knees. Younger subjects take squat posture on EU type. Since 3D SSPP cannot fully model kneeled pose, although estimated load on knees and ankles are not precise, the loads on knees and ankles seem high. Estimated centroid locates forward from foot position (yellow dot of the foot figure).

Slant drum washer-dryer (AQ-1) has the most stable posture. Centroid locates the center of the foot area.

Elder subject's tendencies can be summarized as follows. 1. Avoiding unbalanced posture: younger subjects tend to take posture of one-foot standing or squat, those require more muscular tension. Elder posture is more stable by grabbing or putting hand on washer. 2. By using above strategy, the differences of intervertebrae disk compression (L4/L5) and percent MVC between washers are smaller than young subjects.

VIII. Conclusion

We have evaluated 3 types of washer and washer-dryer with subjective evaluation, posture measurement with motion capture device and load estimation by biomechanical kinematic model. Finally, the comparison of postures between younger and elder subjects was shown.

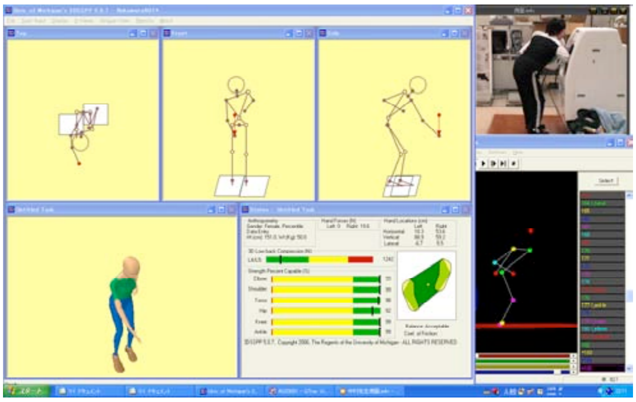
Biomechanical and ergonomic considerations shown here is still not common in product development, but we believe that they are quite indispensable for both product improvement and development strategies, in a context of Gerontechnology.

Table 3: Values estimated by model (151cm elder female)

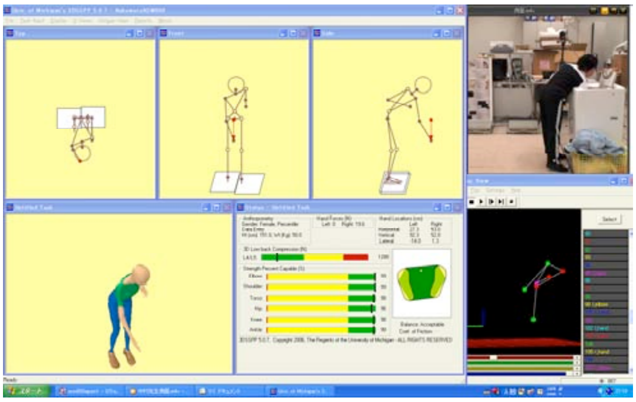
Subject:Elder;151cm /50kg	L4/L5 Comp	%MVC(50 %ile)elbow	hip	Knee	Ankle	
AQ-1	1242	14	45	14	18	
AWD-500	1166	13	43	32	148	<- note
ASW-800	1288	12	34	32	43	

	Sum (%MVC)	Sum(%MVC) /400
AQ-1	91	0.2275
AWD-500	236	0.59
ASW-800	121	0.3025

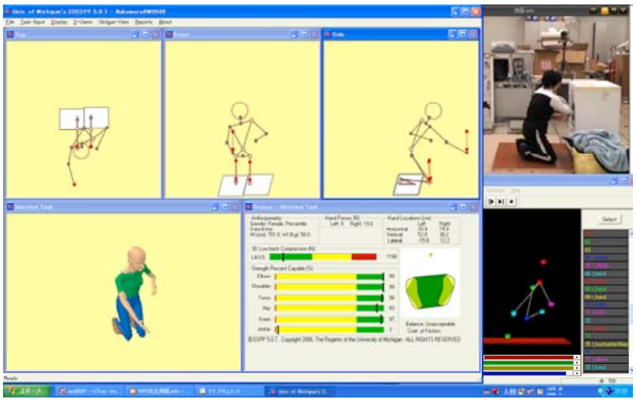
Note: Ankle load of AWD-500 should distribute to both Knee and Ankle



Slanted Drum (AQ-1)



Vertical Drum (ASW-800)



EU type (AWD-500)

Figure 10. Posture and load estimation on the posture of maximum bending (151cm elder female)

REFERENCES

[1] Chaffin, D.B., Andersson, G.B.J. & Martin, B.J.: Occupational Biomechanics (Fourth Edition), Wiley, 2006.

[2] The Research Institute of Human Engineering for Quality Life: Japanese body size data 1992-1994 (http://www.hql.jp/project/size1992/bookdb.html)