Development of a Washer-Dryer with Kansei Ergonomics

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Abstract—**Washer-dryer machines with slanted drums have recently become popular in Japan. Using three-dimensional motion capture devices, we measured and analyzed user posture while using such machines. Subjective Kansei and usability questionnaires were also used. After the measurements, the users' postures were analyzed with a human kinematic model. Three types of machines were used for the experiment: a European-type horizontal-drum washer, a conventional Japanese washer with a vertical drum and a new washer-dryer design with a higher-profile slanted drum. The sum of the estimated percentage of maximum voluntary contraction (elbow, hip, knee, ankle) for the new washer-dryer was 116; it was 133 (knee tension was high) for the European washer and 284 (ankle tension was 110, which exceeds the limit) for the conventional Japanese washer. Subjective fatigue and overall evaluations rated the new washer-dryer significantly better than the European and conventional Japanese washers.**

The operation of an automatic washing machine is complex and difficult because of its many functions. The usability of the control panel on the new SANYO AQ3000 washing machine was also improved. We conducted usability experiments in both the planning and preproduction phases using software and hardware prototypes. The first part of the evaluation using a software prototype highlighted the requirement to clarify the distinction between operating phases. The second evaluation experiment compared between the previous model and a new hardware prototype which buttons were relocated. We confirmed that the result was more usable than the previous model. The new model AQ3000 was released in February 2008 and was well received in the marketplace.

Index Terms—**Kansei ergonomics, Body load, Kinematics, Usability, Interface**

I. Introduction

A. Kansei Ergonomics

Ensuring safety and removing unpleasant items are the immediate tasks of ergonomics. Physical traits, such as torque, acceleration, and vibration, as well as physiological measurements, such as electromyography, are major concerns.

Kansei is a Japanese word that means sensibility, feelings and cognition. Professor Nagamachi began Kansei engineering by combining psychological measurement and analysis methodologies with ergonomic measurement techniques. Kansei engineering is indispensable for successful product development.

Research results produced during the early era of Kansei engineering, from the 1970s to the mid-1990s, were presented primarily in ergonomics societies. We have used Kansei engineering in the development of products since the 1980s.

Since the end of the 1990s, we have been involved in the development of many more products, and have recognized that Kansei engineering and ergonomics are inseparable. Successful products cannot be made with only ergonomic considerations, and Kansei engineering provides eloquent answers to the problems that arise. We are fully convinced of the need for Kansei ergonomics.

B. Washer and Washer-Dryer Machines

Washer-dryer machines with slanted drums have recently become popular in Japan. Japanese washing machines have traditionally had vertical drums, and these are still quite common. The users of vertical-drum washers must bend their backs and stretch their arms to insert and remove laundry. In Europe, on the other hand, horizontal-drum washing machines have long been popular. This type of machine requires the user to crouch to insert and remove laundry because of its lower height.

The new washer-dryer combo machines have horizontal or slanted rotational drum axis. This has resulted in a significant change in shape, and the door position was changed to make loading and unloading easier.

This research compared the physical loads and usability of the new generation of washer-dryer with traditional Japanese and European washing machines. This comparison was performed using subjective evaluations, three-dimensional (3D) motion captures, and estimates of the load on certain body parts using a human kinetics computer model.

Thirty-three percent of automatic washing machines sold in Japan in 2007 had built-in dryers [1]. Factors such as the increased number of working parents and concerns over pollen allergies are likely major causes of increasing sales of automatic washer-dryer machines.

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machines have more functions. Manufacturers tend to provide an increasing number of functions on automatic washing machines to suit changes in family structure and individual concepts of personal hygiene. For example, futons and blankets, which were rarely sent to the dry-cleaners in the past, are now frequently washed at home using the heavy-duty or wool-specific cycles that modern machines offer. Apartment residents often prefer to use quiet washing cycles and the built-in timer.

Sanyo Electric has added a novel waterless cleaning cycle to disinfect and deodorize items with ozone generated in the machine. This cycle is often used for leather wares, shoes and stuffed toys, which were always difficult to clean at home in the past.

As the number of washing machine functions had increased, users require simplified ways of making them work properly. The user interface must help a wide range of users find the functions they want out of the many available, and help them set the program parameters. We have also redesigned the control panel and machine operation based on ergonomic evaluations and analyses.

II. Body Load Evaluation Method

In our experiment, we requested that participants remove laundry from the machines. The standard model laundry load consisted of two dry towels at the bottom of the drum with two dry 1.6-kg blankets placed on top the towels. The participants were asked to open the door, take out the laundry piece-by-piece, put the items into a basket that was placed on the floor, and then close the door. The participants were 12 females, aged 20–43. Four participants were short (148-153 cm), five were close to the young (age 20-29) Japanese female average of 158 cm, and three were taller, around 165 cm.

Figure 1 shows the three different laundry machines used. Note that the opening of the vertical-drum machine faced straight up, meaning that laundry had to be lifted higher than the actual height of the door.

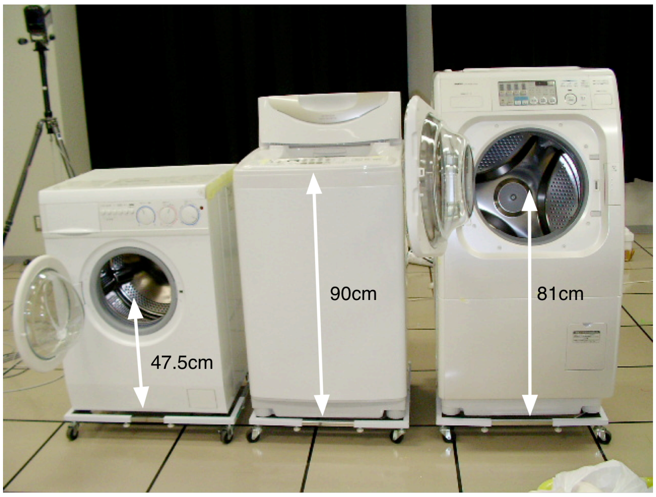


Figure 1. Laundry machines: European-type AWD-500 9 (left), vertical-drum washer ASW-800 (center), and slanted-drum washer-dryer AQ-1. The measurements on each machine are the heights to the center of the opening.

Table 1. Questions for Subjective Evaluation

1. How tired does your entire body feel?
2. How tired are your neck and shoulders?
3. How tired are your upper arms?
4. How tired is your low back?
5. How tired are your knees?
6. How easy was it to push the door open button?
7. How easy was to open and close the door?
8. How easy was it to check inside the drum?
9. How easy was it to insert your hand or arm inside the drum?
10. How easy was it to remove the laundry?
11. How easy was the machine to use?

III. Subjective Evaluation Results

A subjective evaluation was carried out by asking the participants a set of questions each time they completed the task of removing laundry from a machine. Five questions were related to fatigue, five were related to usability, and one final question was related to the general usability of the washing machine. Table 1 lists the questions asked. Each question was answered on a five-point scale.

We used a one-way analysis of variance (ANOVA) to examine whether differences existed between the evaluations of the different washers. For post-hoc pair-wise comparisons, we used the Tukey-Kramer Honestly Significantly Different (HSD) test. Table 2 shows the results; washers are aligned by evaluations in rows. The slanted-drum machine received the highest evaluations for all questions.

Results show that 7 of the 11 questions were significant and that the European-type machine was statistically significantly inferior in terms of user fatigue and ease of use. The results also showed that the vertical-drum machine, which has been widely used in Japan until recently, was not suited for removing laundry from the drum (Q10). We next investigated the relationship between these results and the user's working posture using motion capture.

Table 2. One-way ANOVA and Post-hoc Test Results

Question	1way ANOVA significance	Good <--> NoGood, post-hoc test significance(*)
Q1	√	* * slanted-drum, vertical-drum, European-type
Q2	√	same
Q7	√	same
Q8	√	same
Q11	√	same
Q10	√	* slanted-drum, European-type, vertical-drum
Q6	√	* slanted-drum, European-type

IV. Working Posture Measurements Using Motion Capture and Analysis of Joint Angles

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

Markers were placed at 15 locations on each participant'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 (i.e., on the participant's slippers).

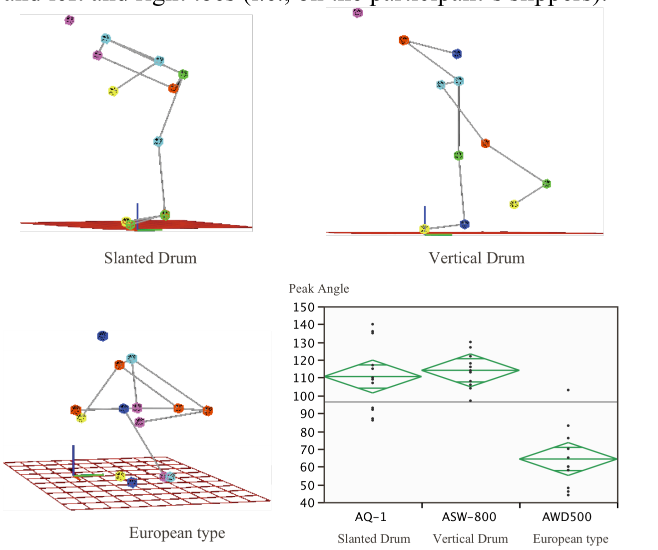


Figure 2: Posture during maximum bending of body (young 158-cm female) and graph of angles formed by the knee, greater-trochanter and shoulder for different machines

Using data from the motion capture, we measured and analyzed the angle formed by the knee, greater-trochanter, and shoulder. This angle was 100° (average of all participants) for the slanted drum, 114° for the vertical drum, and 64° for the European-type horizontal drum (Fig. 2). Because standing posture is close to 180°, the larger angles are better.

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

The angle formed for the slanted drum was 110/64 = 1.71 times larger than that of the European-type, which can be interpreted as a 70% improvement. Laundry could not be inserted or removed from the European-type machine without squatting completely. This is likely the reason for the poor evaluation of this type of washing machine from 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 permitted a posture closer to the vertical stance than that of the slanted drum, but because the vertical drum was deep, almost all of the participants had to lift one foot off the ground and stretch to reach the towel at the bottom of the drum. This is why the vertical drum received a poor evaluation in response to the question "How easy was it to remove the laundry?"

We showed that the vertical drum required an unbalanced posture. The entire body load in such a position cannot be estimated on the basis of coordinates and angle data obtained through motion capture alone. The load on the lumbar vertebra that cannot be directly measured is also an important factor. Thus, to give due consideration to the mass of the various parts of the body, we attempted to estimate such loads using a kinematic model.

V. Static Load Estimates Using a Kinematic Model

We estimated the load on various parts of the body using a kinematic model. To perform these calculations, we used the 3D Static Strength Prediction Program (3D SSPP) developed by a team lead by Prof. Don Chaffin at the University of Michigan. As shown in Figure 3, the Chaffin model features a human body with a basic structure consisting of seven links. These links are the forearm, upper arm, torso (shoulder to lumbar vertebra), sacral vertebra to pelvis, femoral head to knee, shank, and foot.

Using this model, we estimated the pressure (N) on the disk between the fourth and fifth lumbar vertebra and the maximum 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 participant. The participant is most close to average height and weight of twenties to thirties Japanese women. Marker coordinates and the participant's height and weight were used for the parameters of load estimation.

Table 3 and Figure 4 show that the slanted drum required less overall muscle strength, except for the hips. For the vertical drum, the pressure on the intervertebral disk was less than that of the other two machines, because the back was not bent as much. On the other hand, laundry cannot readily 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 also high.

Summing individual %MVCs and comparing the overall %MVC for the different machines revealed that the slanted drum had the smallest value, with a muscle load about 60% less than that of the vertical drum. The European-type machine placed a smaller load on the hip than the slanted drum, but required 2.36 times the load on the knee because of the squatting posture required. These results demonstrate that the slanted drum permitted improved posture.

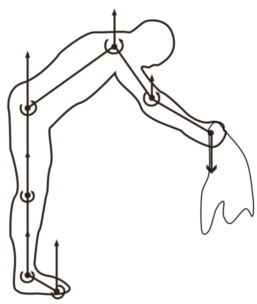


Figure 3. Body links (entire body)

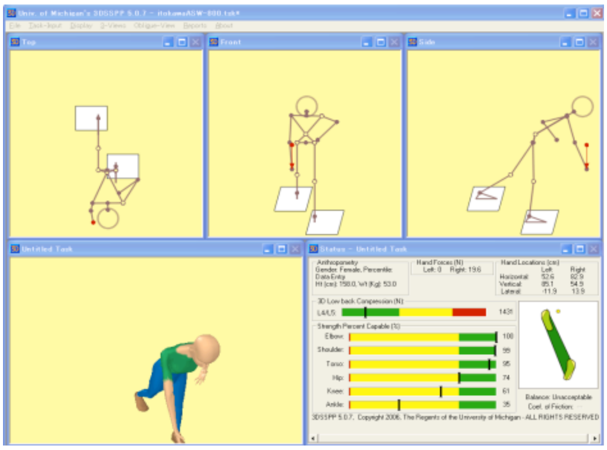


Figure 4. Calculation screen for the vertical drum (158-cm young female)

Table 3. Values estimated by the model (158-cm female)

Participant: 158 cm / 53 kg	L4/L5 Comp (N)	Elbow (%MVC)	Hip (%MVC)	Knee (%MVC)	Ankle (%MVC)
Slanted drum	1732	12	54	25	25
European- type	1801	17	31	59	26
Vertical drum	1431	8	75	91	110
	Sum (%MVC)	Sum (%MVC) / 400			
Slanted drum	116	0.29			
European- type	133	0.33			
Vertical drum	284	0.71			

VI. Usability Experiment using Simulators

We also attempted to examine the usability of the control panel on the new model scince it was planed.

A. Settings

We compared the control panels of the existing model washer (SANYO AWD-AQ2000) and the proposed model prototype (AWD-AQ3000) that included a modified layout and a control knob.

The both panels were implemented as two simulator programs. Those simulators run on Apple PowerBook with a touch screen (TouchSTAR model 15, Troll Touch Inc. and PowerMate, Griffin Technology Inc. for a control knob). Figure 5 shows screen copies of the two simulated panels. Figure 6 shows an overall view of the experimental setup. The participants in the experiment were seven women all over the age of 30 who were accustomed to using automatic washing machines.

The required tasks were the following: turn on the power, select the wash or wash-dry mode, change the washing courses, adjust the wash settings, set the timer, set water-saving mode, and set the "air-washing" function. The instructions given to the participants were, for example, "Set to the machine to wash the wool sweater and then end without drying it" or "deodorize the leather shoes."

The participants were asked to set the designated washing tasks by using two simulator panels. The time and the number of steps to complete each task were measured. Each turn of the control knob of the AQ3000 was counted as one step. The level of irritation on a five-point scale was reported by each participant. All steps were recorded on video tapes.

Hierarchical task analysis (HTA) [3] was performed (Figure 7) to find the erroneous steps of the tasks we conducted. The current alternatives were laid out horizontally and the participants' actual operations were followed vertically. This permitted easy identification of the points where our participants became lost by comparison with the intended (optimal) operating sequence.

The first step was turning on the power switch. This step was drawn at the top of the chart. The next step was determining the function to use. These options were expanded in a row (Fig. 7), connecting to the operation above. Three types of choice or setting were possible: (1) Choice one function from among, wash-and-dry, wash or dry, (2) Choice one of several "Courses" programs for the selected function, and (3) Set the program options: duration for the wash, rinse, spin-dry and dry. The categories of choices or settings were not arranged in a rigid hierarchy, unlike the way many computer programs with graphical user interfaces are designed. Choosing options from a rigid hierarchy in this case would annoy the users because the settings vary widely for the different functions and users.

(a) Simulated panel of AWD-AQ3000.

b) Simulated panel of AWD-AQ2000.

Figure 5. Control panels of the washer-dryers used in the usability experiment.

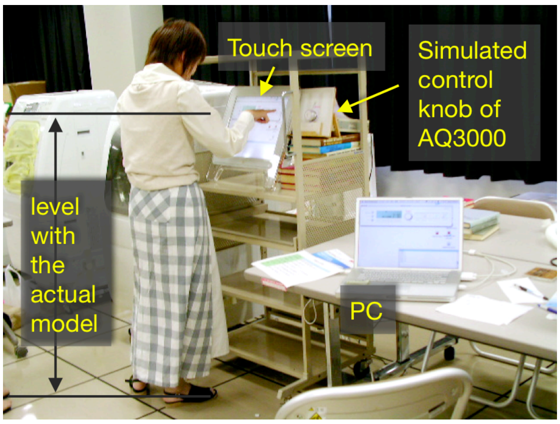


Figure 6. Overall view of the experimental setup.

B. Results

The total level of irritation for all participants and tasks was significantly less on the prototype model (AQ3000) than on the conventional one (AQ2000). The average score of the AQ2000 was 1.93 while that of the AQ3000 was 1.42

($df = 1$, $F = 9.0645$, $p = 0.0032$). The task completion times were not significantly different.

The number of operation steps was reduced using the control knob on the AQ3000, because we found it natural to count a series knob twists without a break as a single step ($df = 1$, $F = 3.6953$, $p = 0.0572$). This feature was appreciated by the participants because they did not have to push buttons many times.

The HTA results highlighted problems in the design of the AQ2000. The "Course" select button caused some mistakes, and this was obvious in such tasks as "10 min wash and dry." HTA of this task is show in Figure 7. A participants incorrectly pressed the "Course" button instead of directly pressing the "Wash options" button. Having the "Course" and the "Wash/Dry Function Change" buttons attract equal attention was problematic. Discriminating among the toggle switching of wash-and-dry, wash, and dry modes was difficult. Two participants turned the power off and started over. The same task was relatively easy using the AQ3000. One subject turned the control knob too many times.

Some participants complained during the post-experiment interview that they often turned the control knob past the desired function because the knob turned too smoothly.

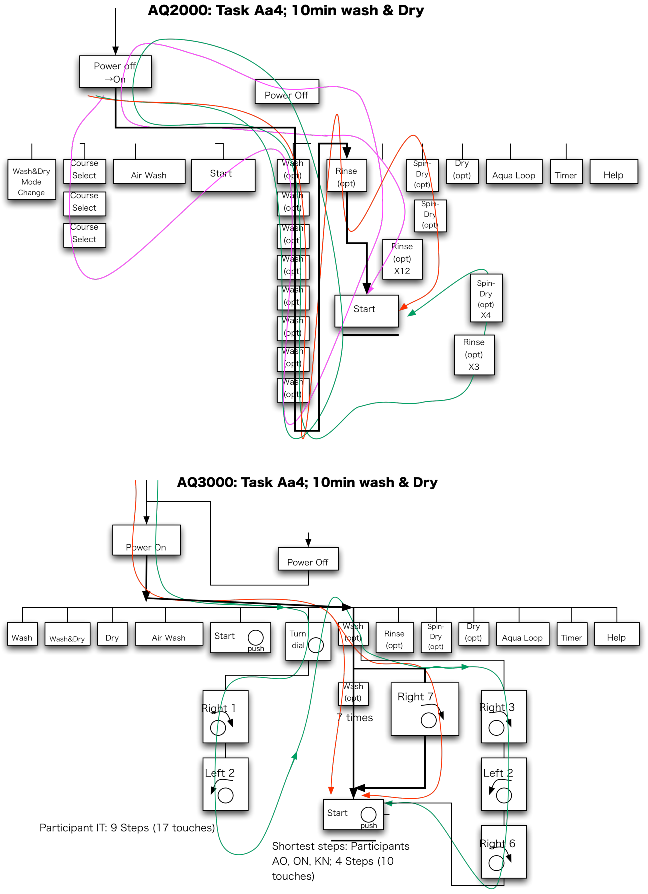


Figure 7. HTA example for the "10 min wash and dry" task. Choice buttons and control knobs (AQ3000) are drawn as connected boxes. The shortest procedure and the sequence that the participant actually performed are indicated.

A. Improvement of the AQ3000

Based on these resuls, we propsed to adopt the control knob and to isolate the mode-selection (wash-and-dry / wash / dry) buttons from the other buttons. The locations of the "Start" button and control knob were also changed. The "Power" button was placed at the right end and the "Start/Stop" button was placed just to its left.

The courses were differentiated from the program options. The courses were appeared in sequence when rotating the control knob. The detailed options were appeared when rotating the knob after pressing one of "Wash options," "Rinse options," "Spin-dry options" or "Dry options". The control knob was also knurled to increase user control.

VII. Association Between Control Knob and Display

A. Settings and Results

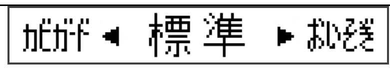
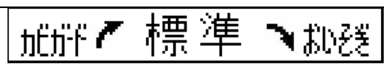
Before starting the usability experiments, we conducted a study of the association between the control knob operation and the display. The participants, 120 university students and teachers age 20-61 were asked which course they expected to be highlighted in the display when they turned the knob clockwise. They described the course they expected on three types of display. Table 4 shows the display types and the number of responses. Display type A had two triangles pointing right and left, similar to railway station signs. Curved arrows on the Type B display also pointed both ways. Curved arrows on the Type C display were associated with rotation. Type B display has smallest discrepancy on the number of response, so this design was used.

B. Comparison to other rotary controls

The compatibility of the association between rotate control and quantitative display is one of classic problems as described in [3]. Wheel-type controls have been used on the new appliances such as the Apple iPod and the Sony

Table 4. Compatibility between display and the rotary control knob.
Question given to the participants: The course "標準 (*hyoujun*; standard washing)" displayed at the center of LCD is now focused. When turning the control knob one division clockwise, which course do you expect to be focused next, "カビガード (*kabi-gaado*; disinfect)" or "おいそぎ (*oisogi*; quick wash)"?


Control knob

Shape of arrows	Display on LCD		
Type A			N.A.
Number of answers	21(17.5 %)	96(80.0 %)	3
Type B			N.A.
Number of answers	13(10.8 %)	105(87.5 %)	2
Type C			N.A.
Number of answers	61(50.8 %)	56(46.7 %)	3

HandyCam to choose one item from the list. In these two examples, rotation and vertical movement are associated; the displayed items are listed in a column and the pointer moves up and down when the user rotates the control wheel counterclockwise and clockwise, respectively.

In the case of our operation panel, one-line display is constrained by the hardware. Then, the new association between control and display in a row is employed, with minimum discrepancy.

VIII. USABILITY EXPERIMENT ON THE PROTOTYPE MODELS

A. Settings

Fifteen male and female washing machine users, aged 30-61, and 25 users about 20 years old participated in the usability experiment. As shown in Figure 8, they were asked to operate to the actual hardware of the conventional model (AQ2000) and the improved hardware prototype model of (AQ3000) to perform six of the seven washing tasks in the first experiment: the use of the water-saving mode was not tested. The time, number of operation steps and the level of irritation were also recorded.

B. Results

The performances on six tasks were compared. Table 5 describes the overall measurement of performance for all participants and all tasks. There was no significant difference in the total completion times for the two models, but the total number of steps and the total level of irritation were significantly reduced with the new model. We tested the difference in the measurements between the models using the Wilcoxon matched-pair signed-rank test, because we found that the distributions were not normal.

We then focused on the performance of the participants 30 years and older because they most closely represent our target market. We found that all measurements were significantly reduced for the new model (Table 6, 7).

In particular, the change in layout and control knob facilitated the task of using the "Air-wash" function (disinfects and deodorizes using ozone instead of water), reducing the average completion time to 34.5% that of the conventional model.

Figure 8. Usability experiment with the hardware prototype models.

Table 5. Comparison between the new hardware prototype (AQ3000) and the previous model (AQ2000) with average measures over all tasks for all 40 participants

Measure / Model	Average completion time	Average steps**	Average irritation**
AQ3000	28.3 s	11.8	1.9
AQ2000	31.1 s	16.4	2.0

Table 6. Comparison between the new hardware prototype (AQ3000) and the previous model (AQ2000) with average measures over all tasks for 15 participants age 30–61

Measure / Model	Average completion time **	Average steps**	Average irritation**
AQ3000	26.3 s	11.2	1.8
AQ2000	34.9 s	18.2	2.2

Table 7. Comparison between the new hardware prototype (AQ3000) and the previous model (AQ2000) for the "Air-wash" task. The measures were averaged over 15 participants, aged 30-61.

Measure / Model	Average completion time **	Average steps**	Average irritation*
AQ3000	12.5 s	3.6	1.3
AQ2000	36.2 s	11.5	2.3

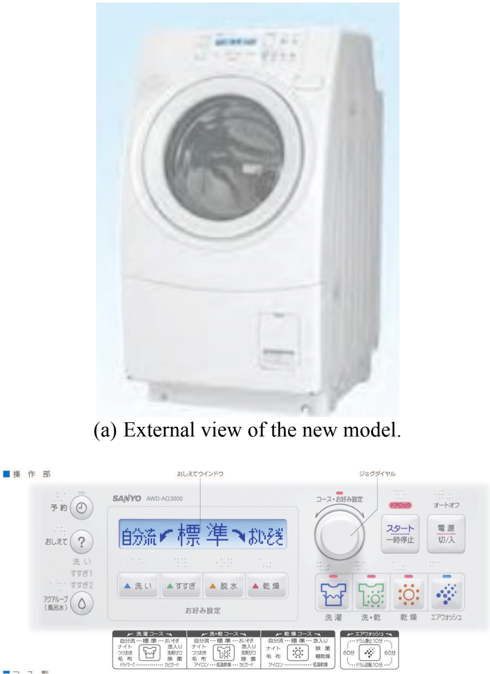
(*$p < 0.05$, **$p < 0.01$)

IX. CONCLUSIONS

We have shown practical case examples of improvement in commercial product development using Kansei ergonomics.

Measurement of working posture showed the evidences of superiority of slanted drum design over the conventional vertical or horizontal drum machines.

In our control panel study, small problems found during the experiment were fixed in the final production model. The colored line on the start button was changed so that it would be easily discriminated from the power button. The final design is shown in Figure 9. The improved new model AQ-3000 was released in February 2008 and became a success in the marketplace.



(a) External view of the new model.

(b) Improved operation panel and the labeling.

Figure 9. Production model of the SANYO AQUA AWD-AQ3000.

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