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The Development of Emotional Flexible Spine Humanoid Robots

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1. Introduction

Over the past 15 years, there has been an increasing interest in humanoid robots. Researchers worldwide are trying to develop robots that look and move more like humans because they believe that anthropometric biped robots have several advantages over wheeled robots. For instance, humanoid robots can communicate with us and express their emotions by facial expressions, speech and body language. They can also work in our living environment without the need of special infrastructure. Moreover, they can serve as companions and take care of the elderly in our aging society. Due to the usefulness of humanoid robots, some research labs and companies, especially in Japan and Korea, have spent an enormous amount of financial and human resources in this research area.

With advances in computer and robot technologies (RT), several impressive biped walking humanoid robots have been developed. For instance, the Honda's ASIMO, Sony's QRIO and the Kawada's HRP-3P. Although these robots are able to walk stably, their movements are not as natural looking as a human's. One of the reasons is that they do not have a flexible spine as we do. Instead, they have a box-like torso. Since it is very difficult to design and control a biped walking spine robot, researchers have been treating their robots as a rigid mass carried by the legs. They neglect the contributions of the spine in daily activities. We believe that in order for the next generation of humanoid robots to better express themselves through body language and to achieve tasks that cannot be accomplished by conventional humanoid robots, they should have a flexible spine as we do.

This chapter is organized as follows. In Section 2 we give an overview of related research on flexible spine humanoid robotics and point out some of the problems faced by researchers in this research area. Then, in Section 3, we describe our approach for solving these problems. In Section 4, we present psychological experiments on the effect of a flexible spine humanoid robot on human perceptions. Finally, in Section 5, we conclude this chapter.

2. Related research

Compared with wheeled robots, it is more costly and difficult to develop biped walking humanoid robots. One of the main reasons is that full-body biped humanoid robots have more joints. Depending on the type of actuators being used, the total development cost could go up significantly. Another reason is that unlike wheeled robots, biped robots need to be able to maintain stability. The task of coordinating different actuators to produce stable walking in a real-world environment is a challenging one.

Based on the concept of Zero Moment Point (ZMP) proposed by Miomir Vukobratovic (Vukobratovic et al., 1970; Vukobratovic & Borovac, 2004), Atsuo Takanishi at Waseda University applied the ZMP criterion to realize stable walking for biped robots (Takanishi et al., 1988; Takanishi, 1993). His approach contributes greatly to the development of walking humanoid robots. In addition to his ZMP-based compensation approach, other methods such as inverted pendulum, central pattern generator (CPG) and passive walking have also been used to control biped humanoid robots (Sugihara et al., 2002; Nagashima, 2003; Kajita et al., 2003; Collins et al., 2005).

Realizing that the spine is very important in daily activities, several research groups have started to build flexible spine humanoid robots. At the University of Tokyo, Mizuuchi attempted to build a full-body humanoid robot which had a spine controlled by eight tendons. However, it looked like the robot could not stand up without external support (Mizuuchi et al., 2001; Mizuuchi et al., 2003a). Mizuuchi then developed a more sophisticated human-size robot called "Kenta" (Mizuuchi et al., 2002; Mizuuchi et al., 2003b). Although the torso of the robot has a spine-like structure, it does not seem to be as flexible as the neck is because it holds heavy electronics and mechanical components. Also, there has been no data to show that the torso is able to move dynamically and by itself while the robot is sitting on a desk. Later, Mizuuchi developed another robot named "Kotaro". The robot is able to bend to the left and right automatically while sitting in a chair.[1] Although Mizuuchi claimed that the robot is able to stand still by itself, there has been no experimental data to support the claim or to show that the robot can move while standing without external support from above (Mizuuchi et al., 2006a; Mizuuchi et al., 2006b). Recently, Mizuuchi has been working on a new robot named "Kojiro" (Mizuuchi et al., 2007; Nakanishi et al., 2007). The robot has only a lower-spine and two legs. Thus far, there is no experimental data to show that the lower-body robot is able to exhibit dynamic motions while standing by itself without external support. Using the same tendon-based approach, Holland and his group at the University of Essex developed the CRONOS series of anthropomimetic robots (Holland & Knight, 2006). However, their robots are also unable to stand up. This shows that building and controlling full-body spine robots using tendons might not be the ideal approach.

At EPFL in Switzerland, Billard and her group developed a new Robota doll for research on human-robot interactions. In order for the robot to communicate with humans more naturally, her group added a 3-DOF spine to the robot (Guenter et al., 2005; Roos et al., 2006). Unlike the robots developed by Mizuuchi, the spine of this robotics doll is driven by hydraulic power. Due to its actuating system, the robot has no mobility. It is fixed on a platform. At the German Space Agency (DLR), Hirzinger and his group developed an upper-torso robot named "Justin". The robot has light weight arms and dexterous hands. Moreover, it has a 3-DOF movable torso. Unlike the tendon-based approach used by Mizuuchi and Holland, each controllable spinal joint of Justin is directly actuated by a DLR ILM DC Motor via Harmonic Drive Gear. Although the robot is fixed on a platform, the added degrees of freedom in the torso allow the robot to manipulate objects both on the floor and on an evaluated shelf (Ott et al., 2006).

In November, 2007, researchers from Sugano Lab of Waseda University announced a new humanoid robot called "Twendy-One". The robot was developed to carry out household

[1] Such movement has been achieved by a few non-flexible spine humanoid robots using only one motor.

work in today's aging society. It has a 4-DOF spine each joint of which is directly controlled by a Maxon DC Motor via Harmonic Drive Gear. Because of the flexibility in the torso, the robot is able to lift a handicapped person from bed. Also, it can handle objects without flattening them due to the 241 pressure sensors embedded in each hand. However, in order to avoid having it fall, the designers fixed the robot on a wheeled mobile platform.

3. Our approach

In the previous section, we mentioned that a few groups worldwide have started to develop flexible spine humanoid robots. However, they have not yet made a full-body walking prototype. Some of their robots cannot even stand up. The main reason for this is that it is very costly and difficult to build a walking spine robot that has a high degree of freedom. Moreover, it is difficult to coordinate all the motors to generate stable walking motions for the robot.

Since our goal is to develop sociable flexible spine humanoid robots that can express emotions through full-body motions, the robots need to be able to stand and maintain balance by themselves without external support. In order to achieve this goal, we need to simplify the mechanical structure of the robots to reduce the weight of the upper body. We need to take an approach different from that used by other groups. Rather than trying to develop robots that have an equal number of spine segments as humans, we have developed robots that have just enough joints to perform all human torso movements. Instead of using tendons or expensive DC motors with Harmonic Drive Gear to control the robots, we use low-cost off- the-shelf RC servo motors.

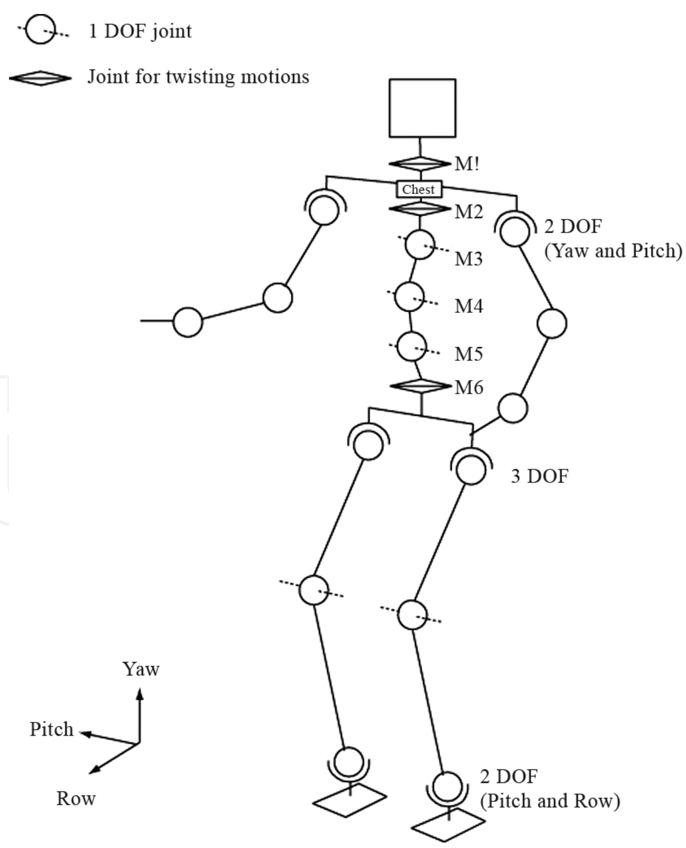

Fig. 1. A schematic diagram of the WBD-1. The robot has 26 DOF joints. Each joint is actuated by a low-cost RC servo motor (from Or & Takanishi, 2005).

Inspired by the dexterity and flexibility of belly dancers, we conducted research on belly dance. After analyzing the motions of professional dancers, we confirmed that a lot of seemingly complex belly dance movements are composed of simple wave-like, circular, sliding motions (Or, 2006). We further noticed that some of the spine motions exhibited by belly dancers are similar to those exhibited by the lamprey, a prototype vertebrate. We then extended our work from belly dance and the motor control of the lamprey to the design and control of flexible spine humanoid robots (Or & Takanishi, 2005). At first, we designed a 6-DOF mechanism that is capable of exhibiting all human-like spine motions with significantly less joints. Then, we added limbs to the mechanical spine to create a full-body humanoid robot called the "Waseda Belly Dancer No. 1" (WBD-1). The spine mechanism of our robot works as follows (see Fig. 1): to generate forward-backward bending on the sagittal plane, we turn motors M3 to M5. To create lateral flexion on the frontal plane, we rotate motors M2 and M6 in opposite directions by 90 degrees. This changes the orientation of the spine so that when we turn motors M3 to M5, the robot's upper torso bends towards the left or right. In order for the robot to twist its body on a transverse plane, we turn motors M2 or M6.
In terms of coordinating different motors in the mechanical spine to generate human-like spine motions, we used a model of the lamprey central pattern generator as the controller. Using the CPG, we are able to control the mechanical spine with only three control parameters (Or & Takanishi, 2005; Or, 2006). Unlike the robots developed by other groups, the WBD-1 is able to exhibit dynamic spine motions even when it is standing without external support. This is accomplished by widening the supporting polygon formed by the feet of the robot.

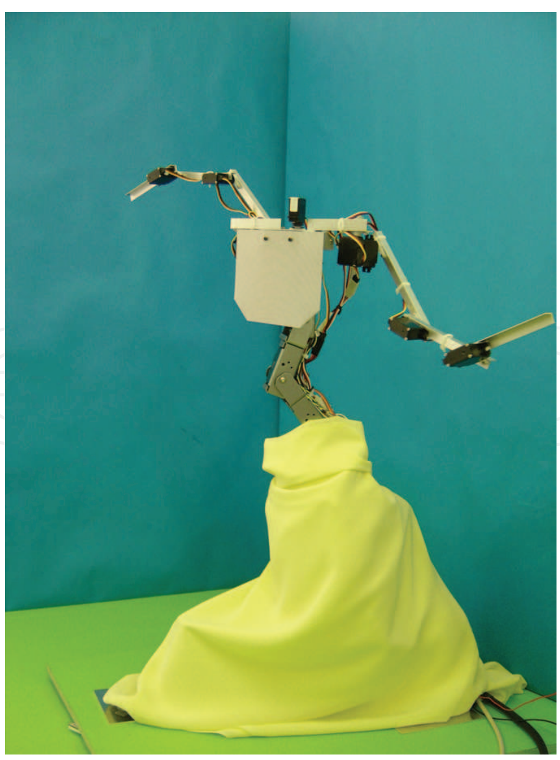

Fig. 2. The WBD-1 performing belly dance (*Nature*, 2004). The robot is able to exhibit dynamic upper body motions without being hung from above.

For emotional expressions using full-body motions, the robots need to be able to maintain balance without external support. To investigate real-time balancing for flexible spine humanoid robots, we developed a hybrid CPG-ZMP based control system for a simple four-segment spine robot (Or & Takanishi, 2004). The robot is made of serially connected RC servo motors. Each motor serves as a spinal joint and the four actuators are stacked on top of each other (Figs. 3 and 4). The motor at the bottom of the mechanical spinal column is connected to a plastic foot-sole. The entire robot is free to move on the desk. In our controller, the biologically-inspired CPG module generates rhythmic belly dancing motions for the mechanical spine. Meanwhile, the ZMP Monitor measures the torque at the base joint. If the torque is larger than an experimentally pre-determined threshold, the robot is on the verge of falling.[2] Whenever this happens, the ZMP Monitor sends negative feedback signals to the CPG module to modulate its neural activities. Depending on the state of the robot and timing, different emergent spine motions can be generated. Using our approach, the robot is able to perform belly dance-like motions while dancing freely on the desk (Fig. 4). The robot's behavior can be interpreted as emotional expressions. For instance, slow wave-like motions correspond to *calm* while fast motions correspond to *happiness* or *excitement*.

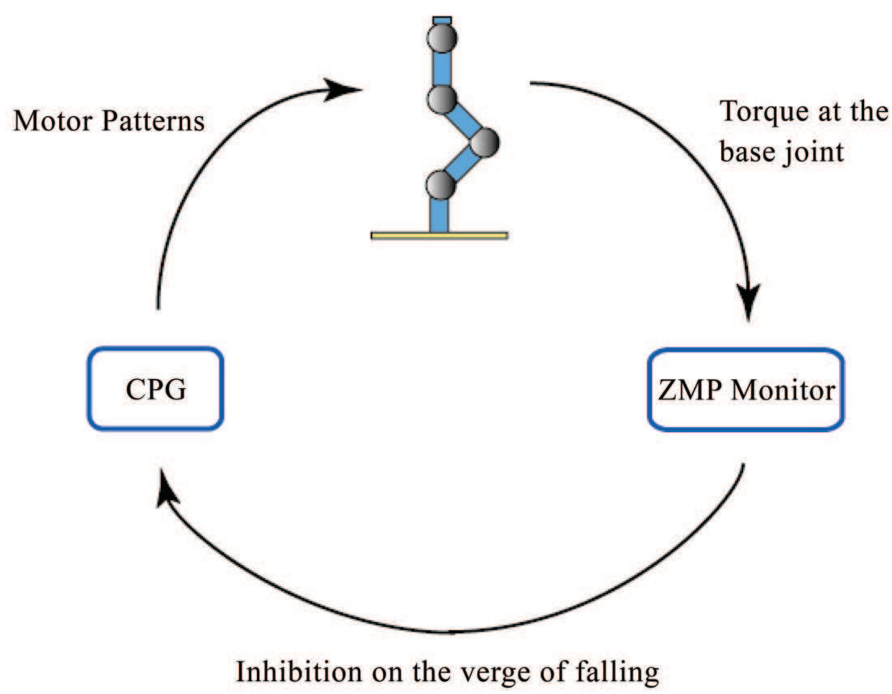

Fig. 3. Schematic diagram of the hybrid CPG-ZMP control system (from Or & Takanishi, 2004).

[2] In our studies, we measured the current consumption of the robot's base joint motor using a current sensor. Since current is proportional to torque and a large torque is generated at the base joint motor when the robot is going to fall, we are able to predict when the robot is on the verge of falling by comparing the measured current with an experimentally pre-determined threshold.

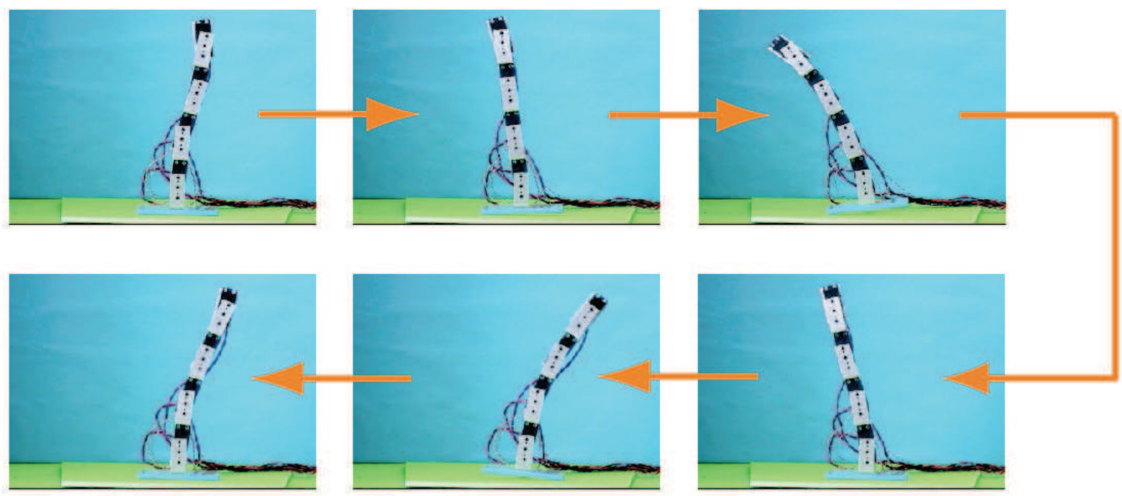

Fig. 4. Snapshot of a four-segment belly dancing mechanical spine controlled by the hybrid CPG-ZMP controller.

Based on the WBD-1, we developed another prototype called the WBD-2 in 2004 (Fig. 5). The robot is capable of expressing emotions using full-body dynamic motions due to an improved lower-body design (Fig. 6). However, because the leg joints are made of low-cost, off-the-shelf RC servo motors, the robot has limited walking capabilities. Later, we developed a new robot called the WBD-3. This robot is able to walk stably at different speeds with dynamic spine motions. In Section 4 of this chapter, we present results of psychological experiments on the effect of an emotional belly dancing robot on human perceptions.

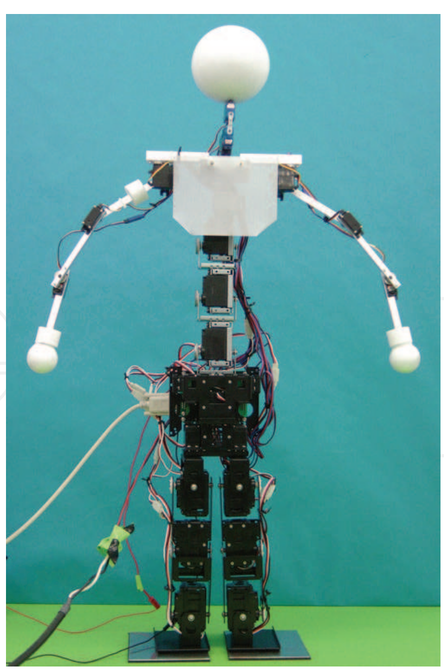

Fig. 5. The Waseda Belly Dancer No.2 (WBD-2) humanoid robot. The world's first full-body, flexible spine humanoid robot capable of full-body motions without external support (as of March 7, 2008).

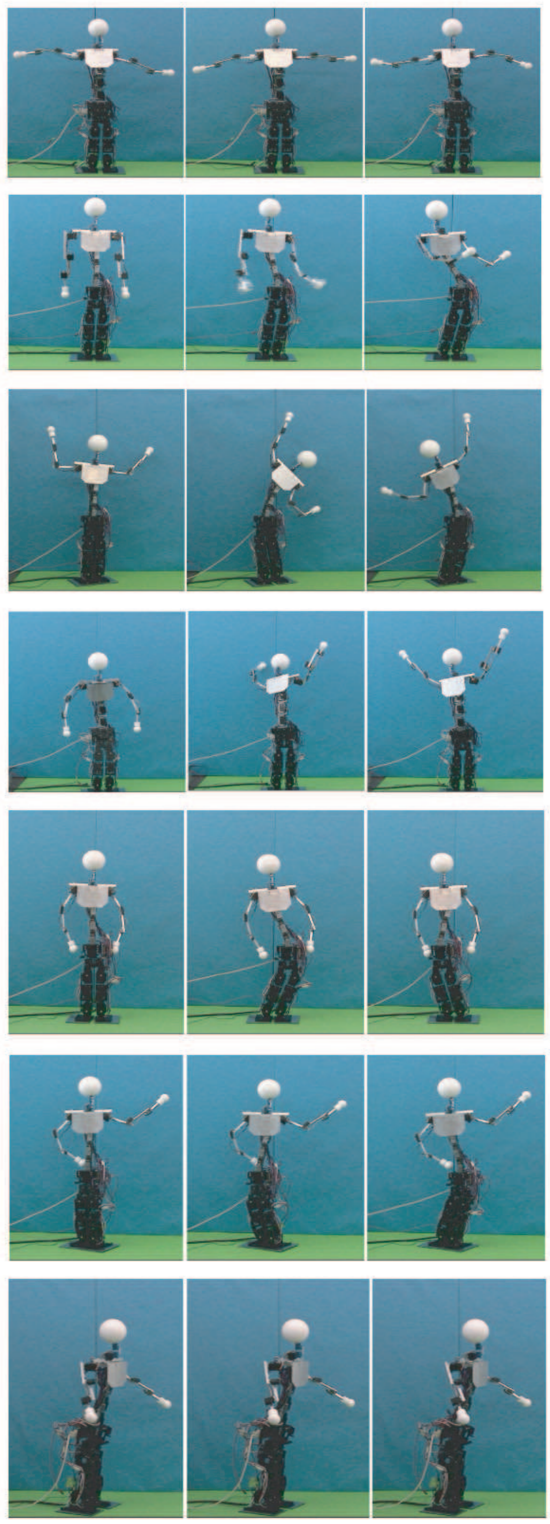

Fig. 6. Emotional expressions of the WBD-2 humanoid robot. Note that the robot is able to exhibit full-body dynamic motions without external support from the top. Behavior for *confident, disgust, happy, relieved, patient, angry* and *sexy* (from top to bottom). For details on behavioral generation, refer to Or & Takanishi, 2007.

4. Experiments on the effect of a flexible spine emotional belly dancing robot on human perceptions

Since much of human communication is non-verbal and we often use body language to express emotions, it is important for humanoid robots to have a similar capability. So far, there have been several studies in the area of communication of emotion from both human and robot body movements (Walk & Homan, 1984; Sogon & Masutani, 1989; Ayama et al., 1996; Dittrich et al., 1996; Brownlow et al., 1997; Shibata & Inooka, 1998; Pollick et al., 2001). Moreover, several impressive robots that can express emotions have been developed (Lim et al., 1999; Kobayashi et al., 2001; Breazeal, 2002; Breazeal, 2003; Itoh et al., 2004; Ishiguro, 2005; Oh et al., 2006). However, besides the WBD-2, there is no humanoid robot that can express emotions using spine motions. We conducted a series of psychological experiments using both the WBD-2 and human actors to investigate whether it is possible for human subjects to categorize effects of the movements of a flexible spine humanoid robot through body motions alone, and how effectively it does so.[3]

4.1 General procedure

Forty subjects were randomly selected to participate in the experiments. The male subjects came from two different labs in the Department of Mechanical Engineering at Waseda University in Japan. Due to the limited number of females in this group, 11 female subjects were also selected from two different dance classes. The age of our subjects ranged from 20 to 34 years old. There were equal numbers of male and female subjects. At the beginning of the experiments, the subjects were provided with three pages of questionnaires (one for each experiment), and they were asked to match a series of video clips to the list of emotions given in each questionnaire, based on their first impressions. They were then shown the video clips on a laptop computer (Thinkpad X40 with a 12.1" LCD screen). Forced-choice paradigm was used. During the experiments, the subjects were not allowed to talk with each other. The experiments were arranged in the following order:

1. Categorization of affective movements from a robot actor
2. Categorization of affective movements from a human actor (with face covered)
3. Categorization of affective movements from a human actor (with facial expressions)

The goals of the experiments were to test whether human subjects could categorize affective movements performed by the different actors. In each experiment, subjects saw a series of seven video clips (Figs. 6, 7 and 8). The videos were arranged in the same order and each of them corresponded to a particular emotion the actor was trying to express. Given that seven choices were provided, the base level at which observers could have been guessing is one out of seven.

In order to statistically test our hypotheses and investigate the patterns of categorizations with respect to the video clips, we used one-way repeated-measures analysis of variance (ANOVA) to analyze the data in each experiment. To carry out the analysis, we used the statistical software program SPSS (version 13.0; SPSS, Inc.). In the analyses described below we follow the convention that a difference is considered to be significant when the p-value of the associated ANOVA test is less than 0.05.

[3] The remainder of this section are orginated from Or & Takanishi, 2007. Copied and modified with permission.

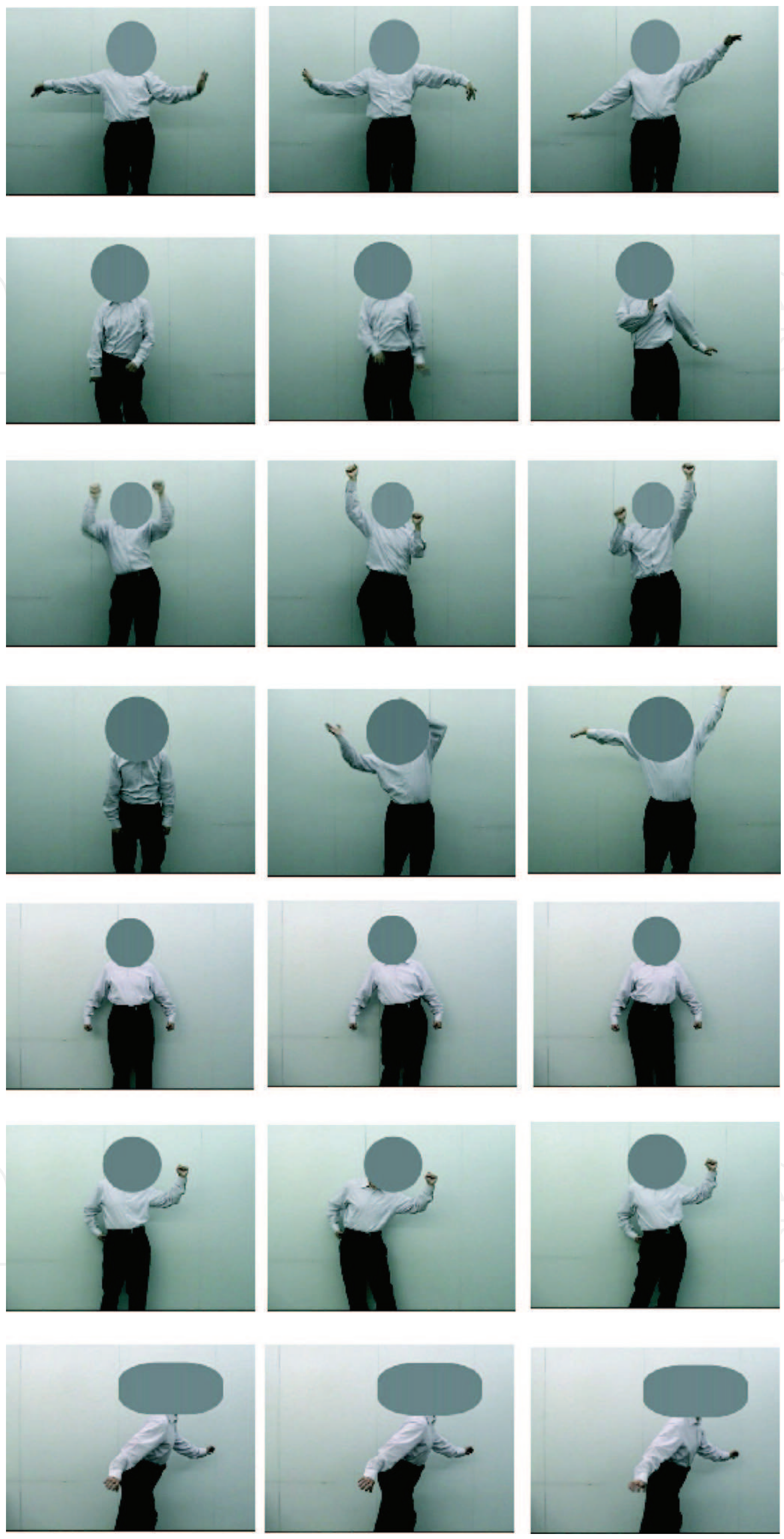

Fig. 7. Snapshot of video images shown in Experiment 2. Movements for *confident, disgust, happy, relieved, patient, angry* and *sexy* (from top to bottom).

Fig. 8. Snapshot of video images shown in Experiment 3. Movements for *confident, disgust, happy, relieved, patient, angry* and *sexy* (from top to bottom).

4.2 Results of experiment 1: categorization of affective movements from the robot actor

The results of our subjects' responses (on an interval scale) are shown in Table 1.[4] We used Mauchly's test of sphericity to ascertain that the assumption of sphericity was met. We then conducted a test of within-subjects effects on how well the movements of the robot actor were correctly categorised. The result shows that there was a significant difference among some of the responses toward the seven affective movements exhibited by the robot. $F(6, 39) = 7.695, p < 0.01$.

Affective Movement	Mean	Standard Deviation	Standard Error of the Mean
confident	(0.150, 0.100, 0.150)	(0.362, 0.304, 0.362)	(0.057, 0.048, 0.057)
disgust	(0.450, 0.375, 0.725)	(0.504, 0.490, 0.452)	(0.080, 0.077, 0.071)
happy	(0.500, 0.725, 0.950)	(0.506, 0.452, 0.221)	(0.080, 0.067, 0.035)
relieved	(0.150, 0.725, 0.625)	(0.362, 0.452, 0.490)	(0.057, 0.067, 0.077)
patient	(0.600, 0.425, 0.625)	(0.496, 0.501, 0.490)	(0.078, 0.079, 0.077)
angry	(0.125, 0.350, 0.475)	(0.335, 0.483, 0.506)	(0.053, 0.076, 0.080)
sexy	(0.375, 0.400, 0.550)	(0.490, 0.496, 0.504)	(0.077, 0.078, 0.080)

Table 1. Descriptive statistics for the responses to each of the emotions expressed by the three actors. Under the columns "Mean," "Standard Deviation" and "Standard Error of the Mean," the elements in parentheses (*from left to right*) represent the responses toward the robot, faceless human and human actor, respectively. Higher mean values correspond to more correct responses.

In order to compare the means of responses to each movement, we examined the pairwise comparisons. Table 2 shows that the movement which corresponds to *happy* elicited significantly more correct responses than the ones corresponding to *confident, relieved* and *angry.* Similarily, the movement which corresponds to *patient* elicited significantly more correct responses than the ones for *confident*, *relieved* and *angry*. Finally, significantly more subjects correctly categorized the movement for *disgust* than the one for *angry*. These results confirmed the hypothesis that a flexible spine humanoid robot can be used to convey recognisable emotions through body movements.

Note that if we take the confidence intervals of the means into consideration, our subjects' responses could roughly be classified into two groups (see Fig. 9). The first group includes *patient, happy, disgust* and *sexy* while the second group includes *confident, relieved* and *angry*.

[4] The raw data can be found later in Fig. 12.

Comparison Pair		Mean Difference	Std. Error	Sig	95% CI
confident	disgust	-0.300	0.103	0.120	[-0.633, 0.033]
	happy	-0.350*	0.098	0.021	[-0.670, -0.030]
	relieved	0.000	0.088	1.000	[-0.285, 0.285]
	patient	-0.450*	0.094	0.001	[-0.757, -0.143]
	angry	0.025	0.084	1.000	[-0.248, 0.298]
	sexy	-0.225	0.104	0.782	[-0.564, 0.114]
disgust	happy	-0.050	0.101	1.000	[-0.378, 0.278]
	relieved	0.300	0.096	0.071	[-0.012, 0.612]
	patient	-0.150	0.098	1.000	[-0.470, 0.170]
	angry	0.325*	0.090	0.019	[0.031, 0.619]
	sexy	0.075	0.121	1.000	[-0.318, 0.468]
happy	relieved	0.350*	0.098	0.021	[0.030, 0.670]
	patient	-0.100	0.112	1.000	[-0.464, 0.264]
	angry	0.375*	0.099	0.011	[0.052, 0.698]
	sexy	0.125	0.125	1.000	[-0.281, 0.531]
relieved	patient	-0.450*	0.094	0.001	[-0.757, -0.143]
	angry	0.025	0.067	1.000	[-0.192, 0.242]
	sexy	-0.225	0.091	0.380	[-0.521, 0.071]
patient	angry	0.475*	0.095	0.000	[0.167, 0.783]
	sexy	0.225	0.091	0.380	[-0.071, 0.521]
angry	sexy	-0.250	0.106	0.490	[-0.594, 0.094]

Table 2. Pairwise comparisons for the performance of the robot actor. *The mean difference is significant at the 0.05 level. Adjustment for multiple comparisons: Bonferroni.

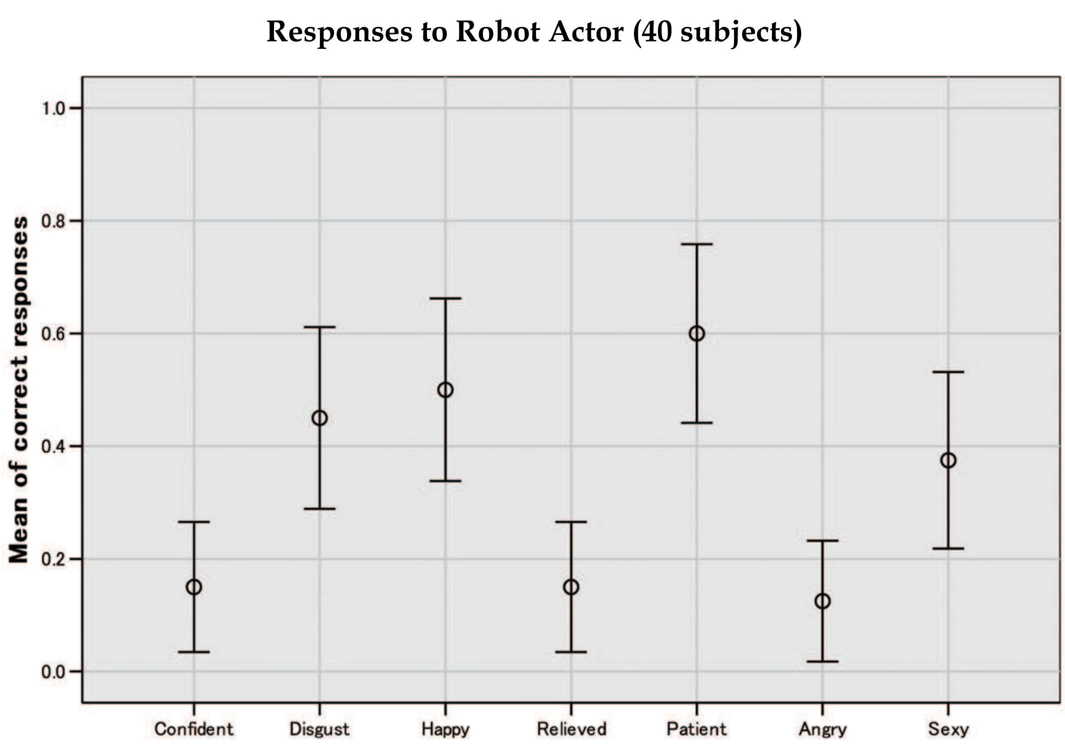

Fig. 9. Responses to affective movements exhibited by the robot. The vertical bars in the graph denote the 95% confidence intervals.

4.3 Results of experiment 2: categorization of affective movements from a human actor (with face covered)

To investigate whether our subjects could categorize emotions from human movements alone, we showed them videos of a human actor performing the same type of movements as the robot. However, in order to prevent the subjects from making their decisions based on facial expressions, we digitally covered the face of the actor.

Table 1 shows the results of our subjects' responses. Mauchly's test showed that the assumption of sphericity was violated (χ^2 (20) = 31.780, $p < 0.05$), so the Greenhouse-Geisser correction was used (ε = 0.824). We then performed the test of within-subjects effects and found that there were significant differences among some of the responses toward the seven affective movements displayed by a faceless human actor. F (4.94, 192.83) = 10.557, $p < 0.01$.

The results of the pairwise comparisons are shown in Table 3. The table shows that the movements which correspond to *happy* elicited significantly more correct responses than the movements for *confident, disgust* and *angry.* Also, the movement which corresponds to *relieved* was significantly more recognizable than the ones for *confident, disgust, sexy* and *angry.* As for the movement for *patient,* it significantly outperformed the one for *confident*. Finally, the movement for *sexy* elicited significantly more correct responses than the one for *confident*. Hence, our analysis confirmed the hypothesis that the subjects could categorize affects based on human body movements alone.

Comparison Pair		Mean Difference	Std. Error	Sig	95% CI
confident	disgust	-0.275	0.088	0.068	[-0.560, 0.010]
	happy	-0.625*	0.078	0.000	[-0.877, -0.373]
	relieved	-0.625*	0.085	0.000	[-0.903, -0.347]
	patient	-0.325*	0.075	0.002	[-0.569, -0.081]
	angry	-0.250	0.086	0.124	[-0.529, 0.029]
	sexy	-0.300*	0.073	0.004	[-0.538, -0.062]
disgust	happy	-0.350*	0.105	0.039	[-0.690, -0.010]
	relieved	-0.350*	0.098	0.021	[-0.670, -0.030]
	patient	-0.050	0.094	1.000	[-0.357, 0.257]
	angry	0.025	0.076	1.000	[-0.222, 0.272]
	sexy	-0.025	0.104	1.000	[-0.364, 0.314]
happy	relieved	0.000	0.113	1.000	[-0.368, 0.368]
	patient	0.300	0.114	0.260	[-0.072, 0.672]
	angry	0.375*	0.106	0.021	[0.032, 0.718]
	sexy	0.325	0.110	0.109	[-0.032, 0.682]
relieved	patient	0.350	0.096	0.071	[-0.012, 0.612]
	angry	0.375*	0.099	0.011	[0.052, 0.698]
	sexy	0.325*	0.097	0.039	[0.009, 0.641]
patient	angry	0.075	0.097	1.000	[-0.241, 0.391]
	sexy	0.025	0.098	1.000	[-0.293, 0.343]
angry	sexy	-0.050	0.107	1.000	[-0.398, 0.298]

Table 3. Pairwise Comparisons for the performance of faceless human actor. *The mean difference is significant at the 0.05 level. Adjustment for multiple comparisons: Bonferroni.

Just like the first experiment, our subjects had difficulty in characterizing the affective movement for *confident*. However, unlike the responses to the robot actor, the responses of our subjects in this experiment can clearly be divided into three distinct groups (see Fig. 10): 1. high performance (*happy* and *relieved*); 2. moderate performance (*disgust, patient, angry* and *sexy*); and 3. low performance (*confident*).

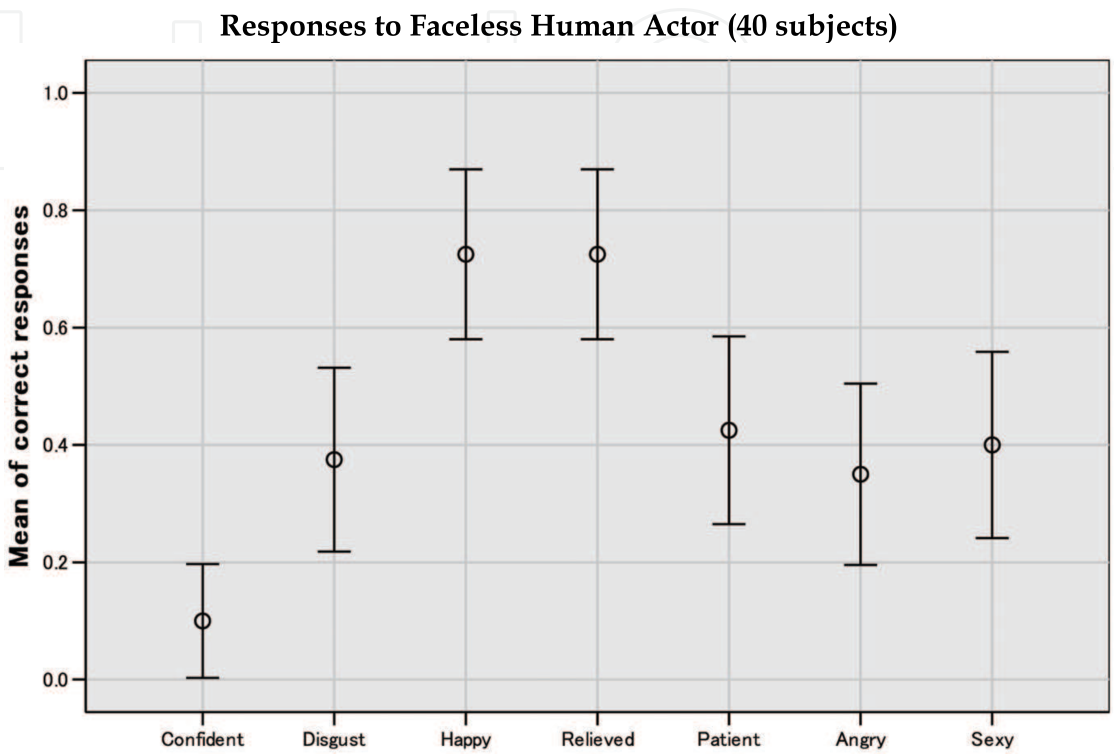

Fig. 10. Responses to affective movements exhibited by a human actor with face covered. The vertical bars in the graph denote the 95% confidence intervals.

4.4 Results of experiment 3: categorization of affective movements from a human actor (with facial expressions visible)

In this experiment, we investigated whether our subjects could categorize emotions from a human actor when they could see the actor's facial expressions. The same video clips used in Experiment 2 were used here, except that in this experiment the face of the human actor was not obscured. We should therefore be able to attribute any change in the pattern of our subjects' responses to the visibility of the actor's facial expressions or due to experience from previous clarification tasks.

Table 1 shows the means and standard deviations of our subjects' responses. Again, Mauchly's test of sphericity indicates that the assumption of sphericity has been violated (χ^2 (20) = 32.967, $p < 0.05$), and again we used the Greenhouse-Geisser estimates of sphericity (ε = 0.826). The result shows that there was a significant difference among some of the responses toward the seven emotive movements exhibited by the human actor. $F(4.957, 193.311) = 13.807$, $p < 0.01$.

Results from the pairwise comparisons are shown in Table 4. The table shows that the movement for *confident* elicited significantly fewer correct responses than those for the other affective movements. Compared with the results from the previous two experiments, this indicates that the poor performance of this movement in all experiments was not caused by the form of the stimulus. Rather, it was caused by a poor choice of movement to express this emotion. The movement for *happy*, on the other hand, was significantly more recognizable than the movements for *relieved, patient, angry* and *sexy*. Its confidence interval is also much shorter than that of other emotive moves. Our analysis confirmed that human subjects were able to categorize emotions from a human dancer with facial expressions shown.

Comparison Pair		Mean Difference	Std. Error	Sig	95% CI
confident	disgust	-0.575*	0.087	0.000	[-0.857, -0.293]
	happy	-0.800*	0.064	0.000	[-1.008, -0.592]
	relieved	-0.475*	0.107	0.002	[-0.824, -0.126]
	patient	-0.475*	0.080	0.000	[-0.735, -0.215]
	angry	-0.325*	0.097	0.039	[-0.641, -0.009]
	sexy	-0.400*	0.093	0.002	[-0.703, -0.097]
disgust	happy	-0.225	0.076	0.108	[-0.472, 0.022]
	relieved	0.100	0.106	1.000	[-0.245, 0.445]
	patient	0.100	0.106	1.000	[-0.245, 0.445]
	angry	0.250	0.093	0.221	[-0.052, 0.552]
	sexy	0.175	0.087	1.000	[-0.107, 0.457]
happy	relieved	0.325*	0.075	0.002	[0.081, 0.569]
	patient	0.325*	0.083	0.008	[0.055, 0.595]
	angry	0.475*	0.088	0.000	[0.190, 0.760]
	sexy	0.400*	0.086	0.001	[0.120, 0.680]
relieved	patient	0.000	0.107	1.000	[-0.349, 0.349]
	angry	0.150	0.098	1.000	[-0.170, 0.470]
	sexy	0.075	0.097	1.000	[-0.241, 0.391]
patient	angry	0.150	0.105	1.000	[-0.190, 0.490]
	sexy	0.075	0.104	1.000	[-0.262, 0.412]
angry	sexy	-0.075	0.097	1.000	[-0.391, 0.241]

Table 4. Pairwise comparisons for the performance of the human actor with facial expressions visible. *The mean difference is significant at the 0.05 level. Adjustment for multiple comparisons: Bonferroni.

As in Experiment 2, the responses of our subjects can clearly be divided into three distinct groups (see Fig. 11): 1. excellent performance (*happy*); 2. good performance (*disgust, relieved, patient, angry* and *sexy)*; and 3. low performance *(confident).*

Just like the previous two experiments, the movement corresponding to *confident* does not lead to a high recognition rate. This might be due to the fact that the movement which we used to represent this emotion is ambigious and uncommon in daily lives. Note that generally speaking, the means of correct responses obtained in this experiment are higher than those obtained in the previous two experiments. In this study, a mean of 0.15 is slightly above chance level.

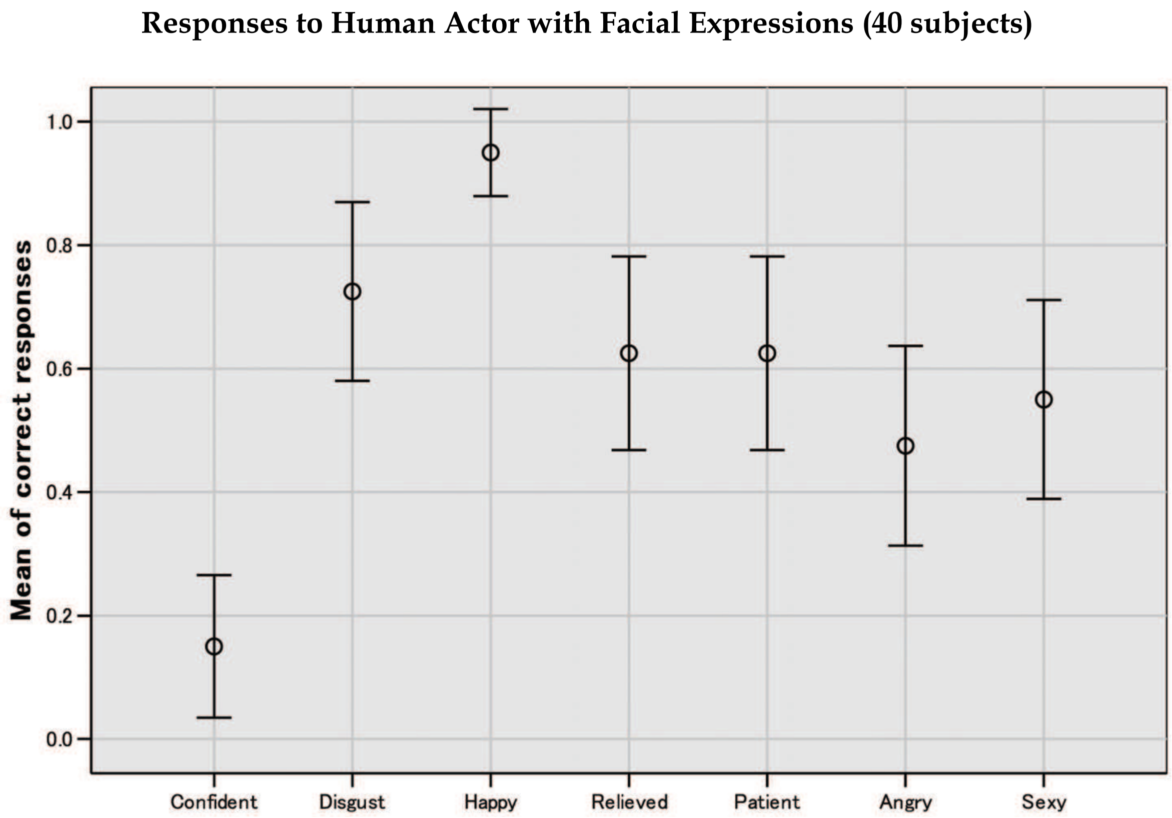

Fig. 11. Responses to affective movements exhibited by a human actor with facial expressions. The vertical bars in the graph denote the 95% confidence intervals.

4.5 Exploration of the effect of type of actor on human perceptions of affective movements

In this section, we are interested in testing the following hypotheses:

1. Does the type of actor influence the overall subjects' responses?
2. Do both human-form actors elicit more correct responses than the robot actor?
3. Does the faceless human actor elicit more correct responses than the robot actor?
4. Does the human with visible facial expressions elicit more correct responses than the faceless human actor?
5. Does the human with facial expressions elicit more correct responses than the robot actor?

To get an overview of how the type of actor affected the overall responses, for each emotion under investigation, we plotted our subjects' responses to each actor as shown in Fig. 12.
In order to analyze the effects of the type of actor on our subjects' responses, we could have done a 7x3 repeated-measures ANOVA. However, this would have resulted in so many interactions that it would have been very difficult to interpret. For this reason we analyzed the data corresponding to each affective movement separately. For each analysis, we conducted Mauchly's test of sphericity and confirmed that the assumption of sphericity was met. The overall results of the effect of different actors on the subject's responses are summarized in Table 5. Our results confirmed the hypothesis that for some movements (*disgust, relieved, happy* and *angry*), the type of actor could influence our subjects' responses.

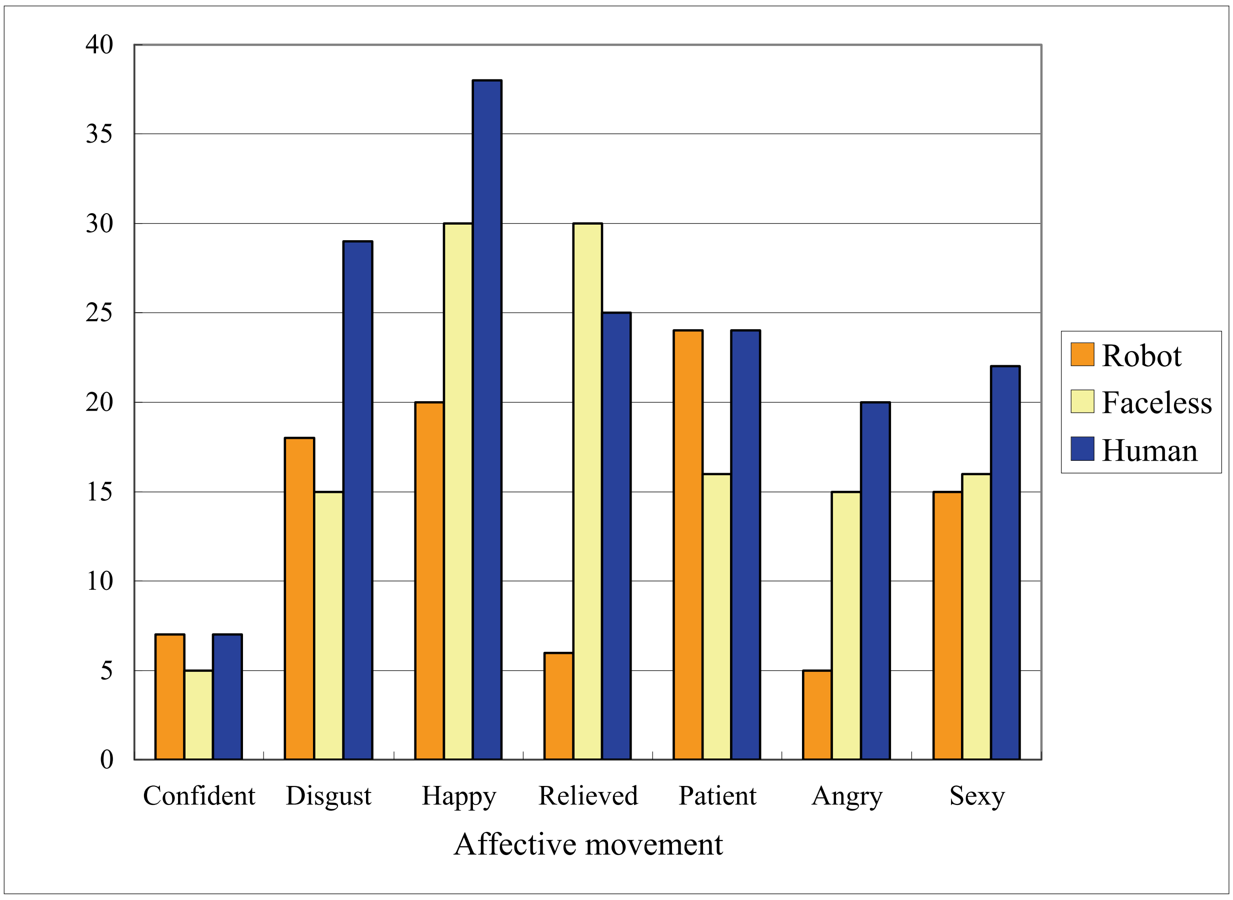

Fig. 12. Responses to movements exhibited by different actors. *Robot* means robot actor. *Faceless* means human actor with face covered. *Human* means human actor with facial expressions visible.

In order to test Hypotheses 2 to 5, we tested subjects' responses to each actor for each affective movement presented. The results of the ANOVA for the within-subjects variable (*actor*) with respect to different emotive movements are summarized in Table 6. The table shows that for *confident,* there was no significant difference in overall responses toward the different actors ($F(2, 78) = 0.358$, $p > 0.05$). However, for *disgust*, there was a significant difference in overall responses based on the type of actor ($F(2, 78) = 5.903$, $p < 0.05$): comparing the means shown in Table 5 shows that for the movements corresponding to *disgust,* having facial expressions visible elicited significantly more correct responses.

Similarily, Table 6 indicates that there was a significant difference in responses toward the three actors' expression of *relieved* ($F(2, 78) = 22.449$, $p < 0.01$). In particular, Table 8 indicates that there were significant differences in performance between the robot vs. faceless human and the robot vs. human with facial expressions. In both cases, the human-form actors performed significantly better. It might be the case that our subjects were more familiar with this movement through their daily interactions with other humans. Interestingly, although the human actors performed this movement more recognizably than the robot actor, there was no significant difference in performance between the two human actors. In other words, showing facial expressions did not significantly improve the recognition rate for this affective movement.

Emotion	Actor	Mean	Standard Deviation	Significant
confident	Robot Faceless human Human with facial expressions	0.150 0.100 0.150	0.362 0.304 0.362	No
disgust	Robot Faceless human Human with facial expressions	0.450 0.375 0.725	0.504 0.490 0.452	Yes ($p < 0.01$)
relieved	Robot Faceless human Human with facial expressions	0.150 0.725 0.625	0.362 0.452 0.490	Yes ($p < 0.01$)
happy	Robot Faceless human Human with facial expressions	0.500 0.725 0.950	0.506 0.452 0.221	Yes ($p < 0.01$)
patient	Robot Faceless human Human with facial expressions	0.6 0.425 0.625	0.496 0.501 0.49	No
angry	Robot Faceless human Human with facial expressions	0.125 0.350 0.475	0.335 0.483 0.506	Yes ($p < 0.01$)
sexy	Robot Faceless human Human with facial expressions	0.375 0.400 0.550	0.490 0.496 0.504	No

Table 5. Summary of the effect of different actors on subject's responses.

Emotion	Source	SS	df	MS	F	Significant
confident	actor error (actor)	0.067 7.267	2 78	0.033 0.093	0.358	0.700
disgust	actor error (actor)	2.717 17.950	2 78	1.358 0.230	5.903	0.004
relieved	actor error (actor)	7.550 13.117	2 78	3.775 0.168	22.449	0.000
happy	actor error (actor)	4.050 12.617	2 78	2.025 0.162	12.519	0.000
patient	actor error (actor)	0.950 13.717	2 78	0.475 0.176	2.701	0.073
angry	actor error (actor)	2.517 12.150	2 78	1.258 0.156	8.078	0.001
sexy	actor error (actor)	0.717 11.950	2 78	0.358 0.153	2.339	0.103

Table 6. Summary of tests of within-subjects effects on the type of actor presented. SS and MS stand for Sum of Squares and Mean of Squares, respectively. Note that *actor* is the repeated-measures variable.

Table 6 indicates that there was also a significant difference in our subjects' responses toward the actors when they were expressing the emotion *happy* ($F(2, 78) = 12.519$, $p < 0.01$). In particular, the human with visible facial expressions elicited significantly more correct responses than the other two actors (Table 9). In contrast, Table 6 shows that there was no significant difference in our subjects' responses toward the three actors when they were expressing *patient* ($F(2, 78) = 2.701$, $p > 0.05$) or *sexy* ($F(2, 78) = 2.339$, $p > 0.05$).
Finally, Table 6 shows that for the movement which corresponds to *angry*, there was a significant difference in responses towards the three actors ($F(2, 78) = 8.078$, $p < 0.01$). Table 10 shows that the human with visible facial expressions elicited significantly more correct responses than the robot actor. However, compared with the faceless human, showing facial expressions did not significantly improve the recognition rate.
Based on the above analyses, a summary of our findings is provided in Table 11. The results indicate that for the affective moves (*disgust, happy, relieved* and *angry*), the type of actor can significantly influence the subjects' responses. Contrary to the common belief that human-form (face and faceless) actors are always able to elicit more correct responses than a robot actor, only the movement for *relieved* agreed with this hypothesis. As for the hypothesis that a faceless human actor is able to elicit more correct responses than the robot actor, this was only confirmed for the movements corresponding to *relieved.* Interestingly, the same human actor, showing facial expressions did not always elicit more correct responses than when the face was covered. In fact, only two (*disgust* and *happy)* out of seven emotive moves showed that this was the case. This calls into question the talents of the human actor and the quality of the human displays. Finally, experimental results show the surprising finding that the human actor with visible facial expressions did not always elicit more correct responses than the robot actor. Of the seven movements under investigation, only those for *happy, relieved* and *angry* did show a higher recognition for the actor with facial expressions over the robot actor. (For discussions on our experiments, refer to Or & Takanishi, 2007.)

Comparison Pair	Mean Difference	Std. Error	Sig	95% CI
Robot, Faceless human	0.075	0.115	1.000	[−0.214, 0.364]
Robot, Human with face	-0.275	0.113	0.059	[−0.558, 0.008]
Faceless human, Human with face	-0.350*	0.092	0.001	[−0.579, −0.121]

Table 7. Pairwise comparisons for the movements for *disgust* performed by the different actors. *The mean difference is significant at the 0.05 level.

Comparison Pair	Mean Difference	Std. Error	Sig	95% CI
Robot, Faceless human	-0.575*	0.087	0.000	[-0.792, -0.358]
Robot, Human with face	-0.475*	0.095	0.000	[-0.712, 0.238]
Faceless human, Human with face	0.000	0.093	0.872	[-0.134, 0.334]

Table 8. Pairwise comparisons for the performance of *relieved* by the different actors. *The mean difference is significant at the 0.05 level.

Comparison Pair	Mean Difference	Std. Error	Sig	95% CI
Robot, Faceless human	-0.225	0.098	0.081	[-0.470, 0.020]
Robot, Human with face	-0.450*	0.087	0.000	[−0.668,−0.232]
Faceless human, Human with face	-0.225*	0.084	0.032	[−0.435,−0.015]

Table 9. Pairwise comparisons for the performance of *happy* by the different actors. *The mean difference is significant at the 0.05 level.

Comparison Pair	Mean Difference	Std. Error	Sig	95% CI
Robot, Faceless human	−0.225	0.091	0.054	[−0.453, 0.003]
Robot, Human with face	−0.350*	0.092	0.001	[−0.579,−0.121]
Faceless human, Human with face	−0.125	0.082	0.400	[−0.329, 0.079]

Table 10. Pairwise comparisons for the performance of *angry* by the different actors. *The mean difference is significant at the 0.05 level.

Hypothesis	1	2	3	4	5
Emotion:					
confident					
disgust	**o**			**o**	
happy	**o**			**o**	**o**
relieved	**o**	**o**	**o**		**o**
patient					
angry	**o**				**o**
sexy					

Table 11. Summary of the analysis of the effect of type of actor on human perception of affective movements. Hypothesis 1: Does the type of actor influence the overall subjects' responses? Hypothesis 2: Do both human-form actors elicit more correct responses than the robot actor? Hypothesis 3: Does the faceless human actor elicit more correct responses than the robot actor? Hypothesis 4: Does the human with visible facial expressions elicit more correct responses than the faceless human actor? Hypothesis 5: Does the human with facial expressions elicit more correct responses than the robot actor? The symbol "**o**" shows that the hypothesis is confirmed for that specific affective movement.

5. Conclusion

Based on the work presented above, we believe that with current technologies, it is unrealistic to build a flexible spine humanoid robot that has as many vertebrae as a human. Also, controlling the robots using the tendons or hydraulic power approach might not be ideal. Our research has shown that by carefully designing the spine mechanism, it is possible to build a flexible spine humanoid robot that can use full-body motions to express emotions. Compared with the robots developed by other groups, the development costs of our robots are relative low. Results from the psychological experiments show that it is possible for humans to recognize the emotions which the robot's movements are intended to express. Statistical analyses indicated that the movements of the robot dancer (WBD-2) are often as recognizable as the movements of the human dancer, both when subjects based their responses on only the movements of the human actor (his face was obscured) and when the human's face was visible along with his movements. Although having the human actor's facial expressions visible does improve the recognition rate for some movements, the availability of the facial expressions does not always elicit more correct responses than the faceless robot actor.

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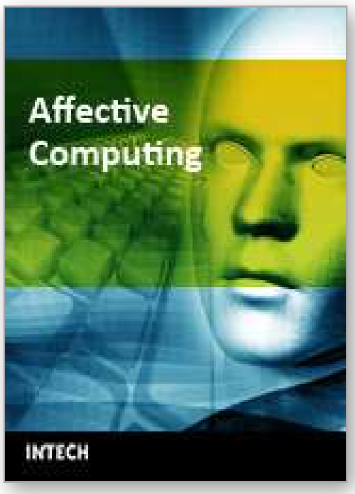

Affective Computing
Edited by Jimmy Or

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This book provides an overview of state of the art research in Affective Computing. It presents new ideas, original results and practical experiences in this increasingly important research field. The book consists of 23 chapters categorized into four sections. Since one of the most important means of human communication is facial expression, the first section of this book (Chapters 1 to 7) presents a research on synthesis and recognition of facial expressions. Given that we not only use the face but also body movements to express ourselves, in the second section (Chapters 8 to 11) we present a research on perception and generation of emotional expressions by using full-body motions. The third section of the book (Chapters 12 to 16) presents computational models on emotion, as well as findings from neuroscience research. In the last section of the book (Chapters 17 to 22) we present applications related to affective computing.

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