Path Analysis for the Halo Effect of Touch Sensations of Robots on Their Personality Impressions

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Abstract. Physical human–robot interaction plays an important role in social robotics, and touch is one of the key factors that influences human's impression of robots. However, very few studies have explored different conditions, and therefore, few systematic results have been obtained. As the first step toward addressing this issue, we studied the types of impressions of robot personality that humans may experience when they touch a soft part of a robot. In the study, the left forearm of a child-like android robot "Affetto" was exposed; this forearm was made of silicone rubber and can be replaced with one of other three forearms providing different sensations of hardness upon touching. Participants were asked to touch the robot's forearm and to fill evaluation questionnaires on 19 touch sensations and 46 personality impressions under each of four conditions with different forearms. Four impression factors for touch sensations and three for personality impressions were extracted from the evaluation scores by the factor analysis method. The causal relationships between these factors were analyzed by the path analysis method. Several significant causal relationships were found, for example, between preferable touch sensations and likable personality impressions. The results will help design robots' personality impression by designing touch sensations more systematically.

1 Introduction

Social interaction depends on various non-social interactions similar to the manner in which verbal communication is supported by non-verbal communication [7]. In social robotics, the physical human–robot interaction typically supports the social interaction between humans and robots [1]. One of the important issues in design of communication robots is the selection of the covering material with appropriate touch sensations to improve the robots' personality impressions. The robots' appearance affects their personality impressions [2,3,12,16]. However, for humans, not only visual perception, but also other modalities may influence personality impressions. Volume and tone are the major components that inform the listener about the emotional state of the speaker [23]. With regard to tactile sensations, the

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touch of products affects their quality impressions and attractiveness. Therefore, it seems reasonable to consider that the touch of robots also influences their personality impressions. Several studies have attempted touch-based interactions between humans and robots [4–6,26], and comfortable covering materials for robots were selected by designers for influencing mental states of humans through the sensation of touch [13–15,18,24]. However, the design of the touch sensation of robots to improve their intended personality impressions is a challenge because how and which touch sensation affect the personality impressions has not been systematically investigated.

Either touch sensations of robot skins [25] or personality impressions [19] of hugging dolls, or both touch sensations and personality impressions of robot hands [8] were evaluated in different conditions, but the manner in which touch sensations affect personality impressions has not been revealed. To systematically understand the causal relationships between touch sensations and personality impressions, we examined the perceived impressions of a robot by using questionnaires with a large number of questions. Figure 1 shows an overview of our research. Participants were instructed to touch and grab the forearm of a robot in a stationary state with their right hand and then answer the evaluation questionnaires on touch sensations (19 items) and personality impressions (46 items). A factor analysis of the evaluation scores was conducted to identify abstract impression factors for touch sensations and personality impressions. A path analysis was then conducted to reveal significant causal relationships from tactile impression factors to personality impression factors.

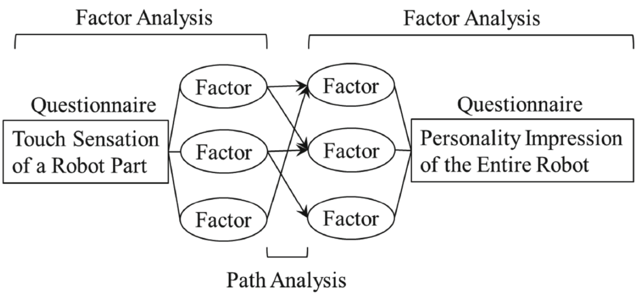


Fig. 1. Diagram of the causal relationship between touch sensations of a robot part and personality impression of the entire robot

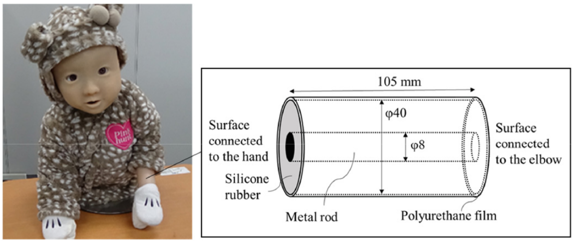
2 Method

2.1 Participants

The participants were 20 healthy Japanese adults, including 10 male (mean age = 21.9, SD = 2.3) and 10 female (mean age = 22.9, SD = 1.2) individuals. Of these, 17 participants had no experience of contact with humanoid robots until the experiment, and 11 participants had no knowledge of humanoid robots. Two participants had contact with infants in the past 5 years.

2.2 Robot

A child-like android robot Affetto [11] was set on a desk in front of a chair as shown in Fig. 2(a). The robot had a head and upper body that were covered with a cloth or gloves; only its face and left forearm were exposed. The joints of the robot were physically fixed to maintain a posture with its left hand held out to the participants so that the joint movements did not affect its impressions. A partition was set so that the robot could be hidden and shown to the participants.



(a) Appearance of the robot (b) Structure of the left forearm

Fig. 2. Appearance of the robot and structural overview of the left forearm

Four different types of left forearms A, B, C, and D with identical sizes and appearances were prepared, and one of them was set between the left elbow and the left hand of the robot for each experimental condition. Figure 2(b) shows the structural overview of the left forearm. Overall, the forearms were cylindrical with dimensions width 40 mm and length 105 mm. The main material of the forearm was platinum cure silicone rubber (Dragon Skin Fx-Pro, Smooth-On Inc.), and its center was supported by a metal rod of diameter 8 mm. The top surface of the silicone rubber was wrapped with a thin polyurethane film of thickness 7 µm (Airwall UV, Kyowa Ltd.) to ensure constant surface friction along the forearm.

Different amounts of two types of additives were mixed into the silicone rubbers to provide different touch sensations to the forearms. One was a plasticizer (Silicone Thinner,Smooth-On Inc.), which reduces hardness, and the other was a thickener (Slacker, Smooth-On Inc.), which increases viscosity while reducing hardness. The additive contents were adjusted so that hardness decreased from forearm A to forearm D, and so that forearms C and D had higher viscosity than forearms A and B. The combinations of amounts a and b of plasticizer a and thickner b were 10 % and 0 %, respectively, for the forearm A, 50 % and 0 %, respectively, for forearm B, 10 % and 30 %, respectively, for forearm C, and 20 % and 30 %, respectively, for forearm D. These percentages mean volume ratios of additives against the silicone rubber before adding them. As a reference, the hardness of forearms B, C, and D measured by a durometer (ASKER Durometer Type FP, Kobunshi Keiki Co., Ltd.) were similar to that of the center of the back of co-contracted forearm of males, the relaxed forearm of males (or the forceful forearm of females), and the relaxed forearm of females, respectively.

2.3 Questionnaire

The semantic differential method (SD method) [21] was used to measure the touch sensations and personality impressions. Two sets of touch sensation questionnaire (TSQ) and personality impression questionnaire (PIQ), each with lists of several pairs of opposite Japanese adjectives, were provided to the human participants. The participants were instructed to choose their responses on 7-point scales between these opposite adjectives, e.g. "Soft or Hard" for the TSQ and "Active or Passive" for the PIQ.

Table 1 summarizes the 19 adjective pairs in the TSQ. Most of these pairs were collected and selected from previous studies on touch sensations of artificial skins with eight adjective pairs [25] and those for robot hands with 10 pairs [8]. Table 2 summarizes the 46 adjective pairs in the PIQ. Most of these pairs were derived and selected from previous studies on personality impressions of robot hands with 12 pairs [8]. In addition to these studies, studies on the impressions of hug dolls with 12 pairs [19], quantification of impressions of humanoid robots with 33 pairs, and meta-analysis of SD adjective pairs for personality impressions [10] were also considered. Thus, our adjective pairs were prepared so that our questionnaires enabled us to investigate touch sensations and personality impressions thoroughly. These adjective pairs were translated into English by a professional translator for this paper.

2.4 Procedure

The experimental procedures were divided into three sessions. In the first one, the participants were instructed on the manner of evaluating the robot. In the second one, they practiced the instructed manner. In the third one, they evaluated the robot by touching its forearm and then answering the questionnaires.

Table 1. Adjective pairs in the touch sensation questionnaire (TSQ)

#	Adjective pair	#	Adjective pair	#	Adjective pair
1	Flabby/Supple	8	Light/Heavy	14	Coarse/Fine
2	Complex/Simple	9	Comfortable/Uncomfortable	15	Good/Bad
3	Dry/Moist	10	Tense/Relaxed	16	Pleasant/Unpleasant
4	Bad-feeling/Good-feeling	11	Blunt/Sharp	17	Elastic/Rigid
5	Soft/Hard	12	Slippery/Sticky	18	Smooth/Rough
6	Large/Small	13	Slim/Plump	19	Rounded/Angular
7	Desirable/Undesirable				

Table 2. Adjective pairs in the personality impression questionnaire (PIQ)

#	Adjective pair	#	Adjective pair
1	Amiable/Odious	24	Masculine/Feminine
2	Humanlike/Machinelike	25	Agreeable/Disagreeable
3	Tiresome/Endlessly entertaining	26	Safe/Dangerous
4	Active/Passive	27	Wise/Foolish
5	Earnest/Insincere	28	Good/Bad
6	Pain-sensitive/Pain-insensitive	29	Quiet/Noisy
7	Kind/Unkind	30	Friendly/Unfriendly
8	Amusing/Boring	31	Merry/Objectionable
9	Lively/Unlively	32	Mild-mannered/Strict
10	Talkative/Reticent	33	Jovial/Gloomy
11	Soothing/Not soothing	34	Convivial/Stiff-mannered
12	Vigorous/Lifeless	35	Extroverted/Introverted
13	Considerable/Self-centered	36	Robust/Feeble
14	Reassuring/Unnerving	37	Laid-back/Busy
15	Young/Old	38	Approachable/Unapproachable
16	Reliable/Unreliable	39	Spritely/Fatigued
17	Bright/Dismal	40	Comfortable/Uncomfortable
18	Docile/Obstinate	41	Clean/Dirty
19	Pleasant/Unpleasant	42	Adorable/Weired
20	Brave/Cowardly	43	Sturdy/Fragile
21	Calm/Restless	44	Neat/Slovenly
22	Desirable/Undesirable	45	Confident/Timid
23	Warmhearted/Cold-hearted	46	Strong/Weak

In the first instruction session, an instruction movie describing the manner of touching the robot and two questionnaires (TSQ and PIQ) were shown to the participants. The movie showed a demonstrator pinching one of the forearms of the robot with his thumb and forefinger, touching it with the pads of his fingers, and holding it with his hand several times. Participants were told to look at the forearm and touch it with their dominant hand as shown in the movie. In the second session, the participants were told to touch their own forearm with their dominant hand and answer the TSQ and PIQ as a training. This section was conducted to check if the participants understood the instructions regarding the manner of touching the forearm and to get to know the questionnaires. The third evaluation session was divided into four subsessions in which the participants evaluated one of the four forearms attached to the robot and the entire robot. In each subsession, the participants were instructed to touch the forearm of the robot for arbitrary time durations and then answer the TSQ. After answering it, they were told to touch it again and then answer the PIQ. This subsession took approximately 10 min. Between subsessions, the robot was hidden from the participants by the partition, and its attached forearm was changed; then, the robot was shown to the participants again. This modification was completed in 1 min. The orders for showing each forearm and the orders of adjective pairs in the questionnaires were shuffled for each participant. The series of these sessions were completed in an hour.

2.5 Data Processing

A exploratory factor analysis was conducted to identify several underlying factors, each of which was statistically reflected by several observed variables or evaluation scores of the adjective pairs. The maximum-likelihood and varimax rotation were chosen for the factor extraction and for the rotation method, respectively. The number of factors chosen based on Scree test was investigated by Bayesian information criterion and the root mean square error of approximation.

Path analysis was conducted to find significant causal relationships between the found factors. Here, we assumed the multivariate multiple regression model whose independent variables were the touch sensation factors, while the dependent variables were the personality impression factors. The maximum-likelihood estimation was used for estimating the model parameters. Version 3.2.2 of R was used for the above analyses.

3 Result

3.1 Factor Analysis

To detect the model structure, the number of dimensions had to be reduced. We conducted factor analyses of each questionnaire by using the number of factors determined by inspecting the Scree plot of eigenvalues. Four touch feeling factors (BIC = -292.2, RMSEA = 0.094) and three personality impression factors (BIC = -2774.5, RMSEA = 0.009) were extracted from evaluation scores of each questionnaire. Tables 3 and 4 list the factor matrices for touch sensation factors and personality impression factors, respectively. Based on the adjectives with high loadings for each factor, we named factor 1 as "Preferable," 2 as "Resilient," 3 as "Smooth," and 4 as "Natural" for touch sensations. We named factor 1 as "Likable," 2 as "Mighty," and 3 as "Vital" for personality impressions.

3.2 Path Analysis

We conducted the path analysis to investigate how tactile feelings affect impressions of a humanoid robot. Seven variables considered were the factor scores calculated from the factor analyses. Satisfactory goodness-of-fit index (RMSEA < 0.001) for a full model including all of the possible paths was achieved.

Table 3. Factor matrix for touch sensation factors; loadings higher than an absolute value of 0.50 are shown in parentheses and those lower than an absolute value of 0.30 are extracted.

Adjective	Factor			
	1	2	3	4
	Preferable	Resilient	Smooth	Natural
Good-feeling	(.97)			
Pleasant	(.97)			
Desirable	(.85)			
Good	(.79)			
Comfortable	.41			
Slippery	.32			
Supple		(.91)		
Tense		(.88)		
Rigid		(.76)		
Hard		(.69)	-.33	
Heavy	-.32	.44		
Large		.32		
Smooth			(.85)	
Fine			(.75)	
Simple			.42	
Rounded			.31	(.59)
Moist				(.52)
Blunt		-.30		(.52)
Plump				.38
Accumulated variance (%)	36	67	86	100

Figure 3 shows the path diagram with standardized partial regression coefficient between touch sensation factors and personality impression factors. Path thickness represents the magnitude of the coefficient. Solid lines and dotted lines represent positive relationships and negative relationships, respectively.

We found that the likable personality was highly and positively affected by preferable touch sensation ($\beta = 0.877$); mighty personality was positively influenced by resilient touch sensation ($\beta = 0.665$); and vital personality was positively affected by preferable and resilient touch sensations ($\beta = 0.385$ and 0.311). Additionally, smooth touch sensation affected mighty personality weakly and negatively ($\beta =$ -0.200); natural touch sensation affected all three personality factors weakly ($\beta = 0.084$, -0.276, and 0.191).

Table 4. Factor matrix for personality impression factors; loadings higher than an absolute value of 0.50 are shown in parentheses and those lower than an absolute value of 0.30 are extracted.

Adjective	Factor			Adjective	Factor		
	1 Likable	2 Mighty	3 Vital		1 Likable	2 Mighty	3 Vital
Desirable	(.99)			Masculine		(.83)	
Agreeable	(.93)			Brave		(.79)	.33
Pleasant	(.90)			Confident		(.78)	.33
Comfortable	(.90)			Neat	.39	(.66)	
Good	(.90)			Obstinate	-.30	(.66)	
Friendly	(.79)			Busy		(.65)	
Soothing	(.78)			Strict	-.31	(.64)	
Approachable	(.75)			Extrovert		(.56)	(.60)
Merry	(.73)			Stiff-mannered		(.59)	
Adorable	(.73)			Pain-sensitive		(.51)	-.41
Endlessly entertaining	(.65)			Talkative			(.82)
Reassuring	(.64)			Noisy			(.81)
Amiable	(.63)	-.33		Jovial			(.79)
Humanlike	(.61)			Bright	.31		(.79)
Clean	(.52)			Active		.48	(.66)
Considerable	(.52)			Lively		.32	(.66)
Robust		(.92)		Spritely	.32		(.65)
Strong		(.91)		Restless	-.49		(.53)
Reliable		(.87)		Accumulated Var	44	76	99

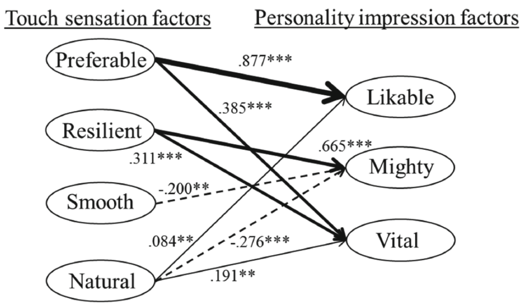


Fig. 3. Path diagram with standardized coefficients representing the relationships between touch sensation factors and personality impression factors. The insignificant paths were removed. ** $p < 0.01$, *** $p < 0.001$

4 Discussion

Several significant causal relationships between touch sensation factors and personality impression factors were identified, in accordance with our hypothesis. In other words, even if a robot has a fixed appearance, its personality impression can be modified by touch sensation. Thus, this study systematically revealed how different touch sensation factors affect different personality impression factors.

First, we found that the likable personality was improved if the robot provided preferable and natural touch sensations to the participants. This supports the conventional idea of covering communication robots with good-feeling and lifelike materials such as fur [13,15,24] and soft silicone rubber [8,17]. In particular, preferable touch sensations strongly affect the likable personality and this emphasizes the importance of designing preferable touch feelings to build likable robots. We consider that the strong causal relationship between preferable touch sensation and likable personality is the result of a type of halo effect, which is known as a human cognitive bias, and is defined as the influence of a global evaluation on the evaluations of individual attributes of a person [20]. Likable personality has been considered as one of the important properties for communication robots, and therefore, several studies have attempted to improve robots' likability by modifying their appearances and behaviors [9,22]. The application of the halo effect by touching robots will be another effective design technique to improve the likability of robots.

Second, the mighty personality was mainly enhanced by imparting resilient touch sensation to the participants. On the other hand, the mighty personality was reduced by smooth and natural touch impressions. This suggests that supple, tight, rigid, and hard covering materials with rough, coarse, and dry surfaces with sharp and squared shapes are desirable to impart the mighty personality to robots. In this perspective, hard covering materials, such as metal, plastic, and hard rubber, are considered to be desirable to enhance the mighty personality of robots.

Here, we encounter a new research question: whether both likable and mighty personalities can be improved using the same covering materials. When we cover robots with soft and comfortable materials, the likable personality will be improved, while the mighty personality will be lost. On the other hand, when we cover robots with hard and unnatural materials, the mighty personality will be improved, while the likable personality will be lost. To improve both personalities, covering materials that can provide preferable and resilient touch sensation simultaneously to humans should be identified.

5 Conclusion

In this study, a factor analysis and path analysis were conducted on the evaluation scores of a robot's touch sensations and personality impressions by using SD questionnaires to reveal how the touch sensations affect the personality impressions such as in the halo effect. Several significant causal relationships between touch sensations and personality impressions were found. The results may help design robots' personality impression by designing touch sensations more systematically. Further studies are required to reveal the types of covering materials that provide preferable touch sensations to humans with several types of robots, including non-android type robots.

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