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# Elderly's preferences towards rehabilitation robot appearance using electroencephalogram signal

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## Abstract

Rehabilitation robots are becoming an important means of assisted living for the elderly, and the appearance of rehabilitation robots directly affects the willingness of the elderly to interact with the robots. Much of the current research on robot appearance preferences relies solely on subjective evaluations, which are relatively cheap, but do not reach deep into the brain to get an accurate grasp of how humans respond to robot appearance. Using electroencephalogram signal and questionnaire survey, we studied the preference of the elderly for abstract and figurative robots. The experimental materials are derived from the pictures of 10 robots in the market. The electroencephalogram signal are collected by BrainVision Recorder and processed by BrainVision Analyzer, as well as SPSS statistical analysis. Experiment shows that the peak of figurative robot pictures is higher and the fluctuation is more intense from 350 ms to 600 ms in the central region and the right half of parietal region. While the peak of abstract robot pictures is higher and the fluctuation is more intense in the prefrontal region, and the difference between abstract robot and figurative robot is not obvious in the occipital region. Based on the electroencephalogram signal and experimental results, it provides the possibility for objective preference evaluation of the elderly to the robot designed features.

**Keywords:** Robots, Electroencephalogram, Objective preferences, Abstract appearance, Figurative appearance

## 1 Introduction

In the past few years, many projects have begun to use rehabilitation robots to solve a series of social problems in family management, rehabilitation monitoring, communication and social interaction [1–3]. In the future, more and more robots will be used to support people's more intelligent life at home. One of the main differences between robots and other household machines or objects is the social interaction between users and the robot. It is necessary to know how to build a close relationship between robots and humans, and how to cooperate actively with the robots. Generally speaking, the current social robot research is mainly focused on expanding the use cases of human robot interaction technology in related fields, such as eye tracking, predictive learning, and human-machine relationship [4–6]. In these studies of robots, robot appearance design is the basis of human-computer interaction, so it has received great attention.

In the product design, the emotional design of the robot shape can make a good user experience, especially in the era of man-machine harmonious symbiosis, the robot with emotional characteristics has increasingly become the urgent need of human life. As an agent, appearance is the physical carrier of all other aspects and has great significance [7–9]. It affects people's first impression and expectation of the robot. There are many questions that can be studied around robot appearance, and one of the issues that are often debated is whether and to what extent smart products should look like people. Several products on the market are designed with consideration for the similarity between products and human body forms, such as bottle, chair, and desk lamp. Anthropomorphism is a method of assigning human characteristics to objects in order to help people understand and interpret their behaviors and abilities [10, 11]. Therefore, it has attracted extensive attention in fields such as information science, cognitive science, art design science, and psychology that robots express emotions through shapes.

In terms of the influence of robot appearance design on human-computer interaction, some people think that for humans and robots to have credible and meaningful interactions, robots should be similar to human beings in structure and function [12–14]. The tendency to use humanoid features as attributes is considered to be a useful tool to enable people to interact with robots. So that researchers begin to pay attention to the classification of robot appearance. In recent years, many types of humanoid robots developed around the world can be divided into two types: those with extremely human-like appearances are generally called "figurative type", while others only have the vague features of the human form are called "abstract type" [15]. In the current research, scholars have studied the influence of robot appearance and human similarity on human emotion. There is evidence that users want robots to be "intelligent machines" that can show more humanoid communication skills, but not like human beings in appearance [16–18]. Through these studies, it is found that the robot head shape is more likely to stimulate good impression if it is close to the baby's head shape. However, robots that look like but not human can seem strange and weird. This phenomenon is often explained in the context of the uncanny valley hypothesis. This is a theoretical hypothesis that explains the human emotional response to robot design. It is believed that if a robot looks like a human, but not enough to evoke a sense of familiarity, it may look like a terrible creature. These findings have a considerable impact on the field of robot design because they mean that robots close to humans may cause unwelcome, negative, and emotional reactions. Therefore, robot design is not only a design science, but also a cognitive science.

Affective processing in the human brain is receiving more and more attention. People focus on robots that look more attractive, and the first impression of these robots is stable for a long time, which also means that humanoid robots with excellent appearance design will inspire positive emotions in users [19, 20]. And these positive emotions are controlled by the left frontal cortex, while negative emotions depend on the full function of the right frontal cortex [21, 22].

More and more, research is concerned with the design implications for the desired end-user groups, whether children, adults, or the elderly [23, 24], looking at the appearance design of robots from their point of view. In addition, there was a difference between young and older respondents: the older the elderly, the less they liked the appearance of a human being [25].

However, at present, the research on robot appearance preference is mainly based on questionnaires measurements, interviews, behavioral experiments, and few studies use advanced neuroscience measurement instruments to enter the level of cognitive neuroscience [26, 27]. In comparison, the cost of subjective measurement is relatively low, but it does not go deep into the human brain to accurately grasp the mechanism of human response to the appearance of the robot. Studies have shown that in many cases, questionnaire responses are affected by external factors and may be changed intentionally by the interviewees, rather than the initial direct brain response [28]. In the past few years, researchers have also been interested in using brain-imaging tools to provide objective data to determine the possible relationship between robot appearance and preferences, rather than simply asking people what they like. In this way, cognitive neuroscience goes deep into the interior of the human brain, which can explore the neural response process and cognitive mechanism of people to things, and then make the research go deep into a more scientific and accurate basic level. In this respect, electroencephalogram is a fairly objective approach to know people's perception process and processing mechanism of robot appearance from the brain cognitive level [29]. By using electroencephalogram, it is possible to understand their emotional state when they are looking at different robot designs.

Event-related potentials are a good method for facial perception analysis. In the field of design, there has been some work that uses these methods to study aesthetic preferences. The brain response related to preference and rank of faces is that the emotional judgment process precedes the cognitive process [30]. In other words, before we make a conscious choice about a robot, we have unwittingly given the answer in advance. Event-related potentials can assess the neural response to emotional events at millisecond time resolution, and we know that decisions to like/dislike are made milliseconds before we really realize it [31].

In summary, the existing research still lacks enough understanding of people's preference for the appearance of robots. Most of these studies use questionnaires with closed questions to investigate this question, which may bring some bias to the experimenter. Considering these questions, we decided not to find the answer directly through specific questions (for example, what kind of robot do you like). Instead, we try to explore some of the aesthetic criteria of robots by collecting people's electroencephalogram responses to different types of robots.

## 2 Materials and methods

### 2.1 Participants

In this experiment, a total of 10 participants were recruited to investigate the elderly responses to the appearances of robots (5 males, 5 females; mean age M = 61.4, standard deviation = 1.2), among which 7 had no background in art design and 3 had some background in art design. They were all right-handed and had normal or corrected vision. In structured interviews, none of the participants reported current neurological or psychiatric illness or related drug intake.

### 2.2 Stimuli

Eighteen pictures of robot products have been collected from the Internet, not including pictures of robot products that do not contain special design factors and are highly realistic with human beings. After excluding the pictures of products with similar appearance, a total of 10 typical pictures were selected as stimulating materials. According to the appearance characteristics of robot products, 10 robot pictures are divided into two groups: abstract group and figurative group. S1 ~ S5 is an abstract group, a kind of robot without realistic humanoid shape, which is easily regarded as a machine. However, it will have some stylized human-like features, such as simplified facial features, eyes, ears, and eyebrows. S6 ~ S10 is the figurative group; the appearance of the robot is technically as close as possible to the real human appearance, including arms, hands and legs.

### 2.3 Procedure

First of all, we briefly introduce the experiment to the subjects and ask them to sign the consent form. Then each subject wears an electrode cap and smears conductive ointment. After all the preparatory work, the actual experiment began. Fast sequence visual presentation task paradigm was used in the experiment. Ten robot pictures appeared randomly on a 60-Hz 22-inch monitor which is about 90 cm away from the subjects. All photos are played in three rounds, and each photo is played six times in each round. The observation time of each picture was 5 s, and subjects were asked to score the first impressions of the robot, including like/neutral/dislike. Electroencephalogram signals are used to detect the subjects' preference pattern.

### 2.4 Date acquisition

The electroencephalogram measurements consisted of 14 blocks, as shown in Fig. 1. It has been found that most electroencephalogram analyses related to cognition are concentrated in the prefrontal, central, and parietal regions, so in this study, the electrodes are located in the prefrontal region (F3,F*z*, F4), the central region (C3, C*z*, C4), the parietal region (P3, P*z*, P4) and the occipital region (O1, O*z*, O2). Fz was used as the online reference, and electrode impedance was maintained below 5 KΩ. Electroencephalograms were acquired with BrainVision Recorder (Brain Products GmbH, Gilching, Germany). The sampling rate was 500 Hz.

### 2.5 Date analysis

For subjective ratings of robot appearance, we performed a separate repeated measures analysis of variance with agent type (abstract group and figurative group) as the factor. We used a BrainVision Analyzer (Brain Products GmbH, Gilching, Germany) to analyze electroencephalogram data. The raw electroencephalogram data were bandpass filtered (0.1 ~ 30 Hz) and re-referenced to the average of the left and right mastoid electrodes. The artifacts such as ophthalmogram and dermatoelectricity were removed, and the wave map and topographic map were drawn according to the degree of preference and the type of image stimulation. The amplitudes of different conditions and different brain regions were extracted and statistically analyzed by SPSS 22.

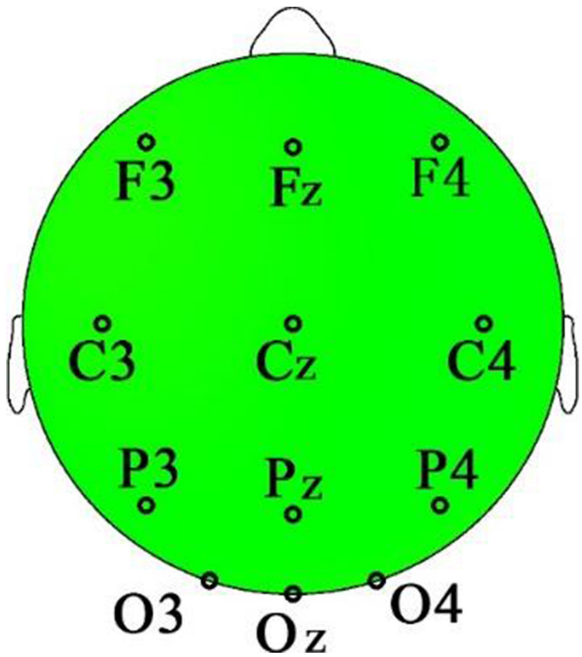


**Fig. 1** Electrode distribution position

## 3 Results

### 3.1 Preference data

Subjects' preference for robots with abstract appearance is like 74.4%, neutral 16.7%, dislike 8.9%, and they think that the reasons why they like abstract robots most are "cute," "simple and honest," and "easy to approach." Subjects' preference for robots with figurative appearance is like 13.3%, neutral 25.6%, dislike 61.1%, and the subjects thought that the most reasons for disliking figurative robots were "panic," "bulkiness," and "hostility."

### 3.2 Event-related potentials

Figure 2 shows the superimposed average waveform of different region. Figure 3 represents the electroencephalogram topographic maps of the two types of robots, and the color depth represents the degree of activation of the brain region. We can know from these two pictures that the peak of figurative robot pictures is higher and the fluctuation is more intense from 350 ms to 600 ms in the central region and the right half of parietal region. While the peak of abstract robot pictures is higher and the fluctuation is more intense in the prefrontal region, and the difference between abstract robot and figurative robot is not obvious in the occipital region.

Select pictures S1 and S10 which have obvious differences from 10 pictures and were selected as the representatives of abstract and figurative types, and then compare the electroencephalogram data of the two pictures, as shown in Fig. 4. S1 elicit a stronger N170 and the P300 of S10 is relatively stronger by comparing S1 and S10.

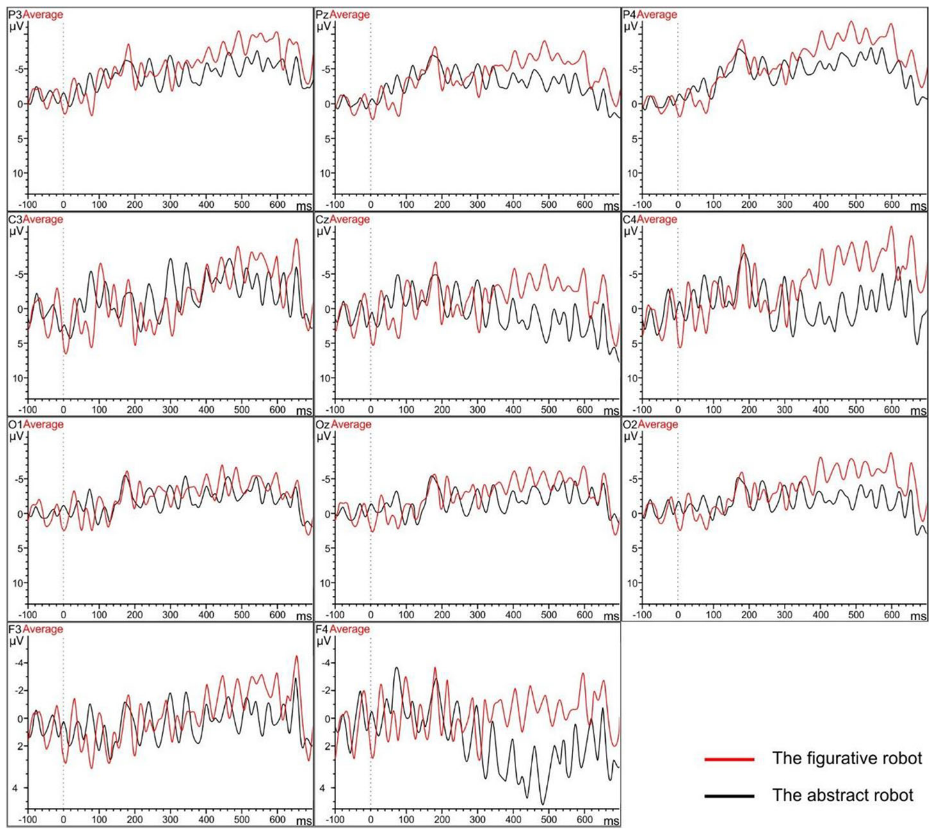


**Fig. 2** Average waveforms of different regions of the head

### 3.3 Statistical results

Under the condition of visual stimulation of different types of robot pictures, the average amplitudes of multiple electrodes in four brain regions were calculated respectively. Because the amplitude fluctuates with time, the time window for extracting the amplitude must be limited. In this paper, we take the peak time point of the waveform as the center and set a time window in the range of ± 10 ms, the amplitudes of N170, P300, andN400 are extracted and statistically analyzed to compare the differences of the amplitudes of the two types of robots.

Taking the type of robot product image as independent variable and the amplitude of each brain region as dependent variable, the paired sample test was carried out. The results show that there is a significant difference in the amplitude of the N170 component in the prefrontal region under different picture types ($t$ = − 1.07, $p$ = 0.04), indicating that the difference in the picture type has a main effect on the composition of the prefrontal region. There is no significant difference in amplitude among the central region ($t$ = − 1.95, $p$ = 0.10), the prefrontal region ($t$ = − 1.38, $p$ = 0.63), and the occipital region ($t$ = − 1.34, $p$ = 0.34). Under the condition of different picture types, the amplitudes of P300 components in the parietal region ($t$ = − 1.07, $p$ = 0.06), central region ($t$ = 2.42, $p$ = 0.14), parietal region ($t$ = 1.53, $p$ = 0.18), and occipital region ($t$ = 2.86, $p$ = 0.11) were not significantly different. Similarly, under the condition of different picture types, the amplitudes of N400 components in the parietal region ($t$ = 3.51,

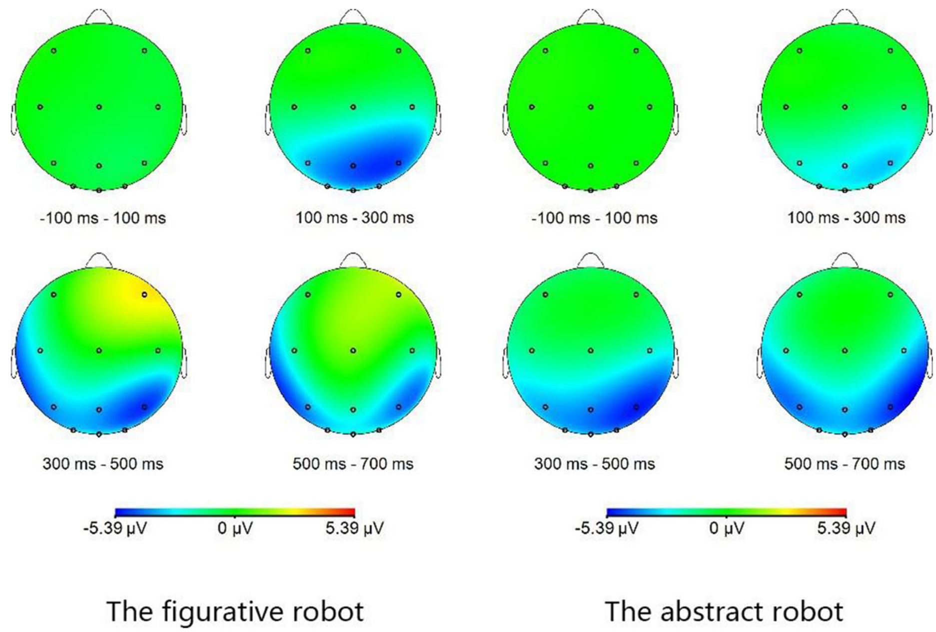


**Fig. 3** Electroencephalogram topographic map of two types of robots

$p$ = 0.12), central region ($t$ = 5.37, $p$ = 0.33), parietal region ($t$ = 4.59, $p$ = 0.25), and occipital region ($t$ = 2.40, $p$ = 0.42) were not significantly different.

## 4 Discussion

From these research results, we can discuss two contents in further detail. The first is the influence of the appearance of the robot on people's preferences. Secondly, how to incorporate the preferences of end-users into the robot appearance design process.

### 4.1 Human preference for the appearance of robots

According to the experiments, the brain's cognitive process of robots is that at 170 ms, and there are more emotional expressions contained within stimulation of abstract robot pictures, and induce early top-down regulation from neural systems involved in rapid emotional processing. And after 300 ms, the elderly pay more attention to figurative picture than abstract ones. Combined with the statistical results of the image preference of abstract and figurative robots, it can be seen that the design features of abstract products are simple, they are just similar to human beings in appearance and action to a certain extent and require less attention, and are more likely to stimulate positive emotions. On the contrary, some of the figurative robots are too close to the real human body and have more design features, so the elderly need to pay more attention and they are very likely to enter the range of uncanny valley. Even if there is only a slight difference between the figurative robot and the human being, it will be very conspicuous and dazzling, so that the whole robot has a very stiff and scary feeling. And the electroencephalogram experiments show that the negative emotions mainly depend on the function of the right parietal region.

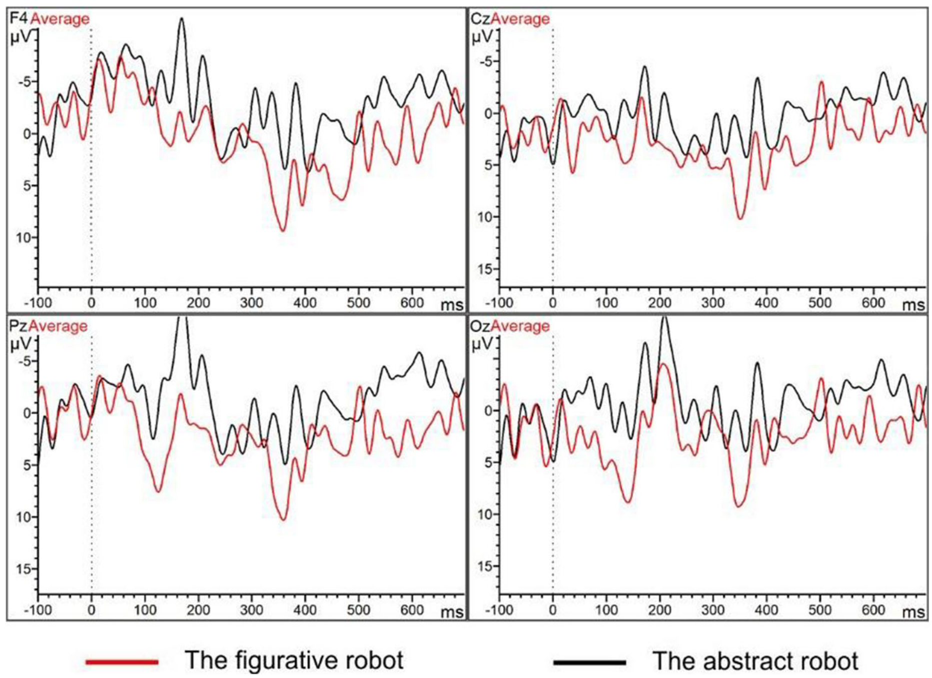


**Fig. 4** Electroencephalogram topographic map of two types of robots

Although in theory, it is possible to cross the uncanny valley by being more similar to humans, the elderly seem to prefer robots that are simple and easy to understand and more easily integrated into the home environment. This kind of abstract robot, which looks different from human, but has some human characteristics, can make the interaction between people and robot more intuitive, pleasant and easy. This is mainly because the elderly usually use similar information and assumptions to form mental models about robots. A robot must be able to perform a series of useful tasks or functions. And in order to share the environment and interact with people, the execution process must be completed in a socially acceptable, comfortable, and effective way. If a robot is exactly like a human in appearance and behavior, then the elderly have reason to assume that humans will treat it like other humans and expect it to act like a human. And if the appearance of a robot is not exactly the same as that of a human, then the elderly will react to it in the same way as they do to pets. They can tolerate problems such as not intelligent enough and flaws in their work.

### 4.2 Robot appearance design for the elderly

The appearance of the robot for the elderly is not entirely determined by its function and technical ability, it will also be affected by specific aesthetic and design features. The appearance of robots affects human perception of robots to a great extent, so designers can draw conclusions from the older adults' tastes and preferences to measure the attractiveness of some features in robot design. From the point of view of industrial designers, creating the right robot shape is the most important thing. If designers can create the right robot, people will be more receptive to robots in their daily life. However, it is also very difficult to visualize the functions of robots to express positive images and establish close relationships with people. Therefore, designers have more and more responsibility in robot design.

For rehabilitation, robot that have appeared in the older adults' lives at present and will appear in large numbers in the future, when designing them, the prototype should tend to not only be anthropomorphic, but also looks like a machine, avoiding the uncanny valley effect. This is a problem that all of us who are concerned about robot and the development of this industry need to pay attention to. Designers might as well regard the robot as a kind of intelligent household appliances; on the one hand, it can minimize the contrast between the robot and the older adults' ability defects. On the other hand, the appearance of the robot affects people's evaluation of the ability of the robot, and also has an impact on the accessibility, desirability, and expressiveness of the robot.

## 5 Conclusions

The rehabilitation robots appear more and more in the older adults' life scenes, and the appearance design of robots plays a very important role in the emotional experience of the elderly. Through electroencephalogram experiments, the elderly are more likely to like the abstract appearance, and have a low preference for the figurative appearance, which may even arouse users' fear. Therefore, for designers, robot appearance should not look too similar to a human, so as to make the interaction between the elderly and robot more intuitive, pleasant, and easy.

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#### Authors' contributions
Both authors have contributed towards this work as well as in compilation of this manuscript. The authors read and approved the final manuscript.

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#### Availability of data and materials
Unfortunately, the data are not available online. Kindly, contact the corresponding author for data requests.

### Declarations

#### Consent for publication
Informed consent was obtained from all authors included in the study.

#### Competing interests
The authors declare that they have no competing interests.

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## Publisher's Note