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Research article

Exploring the influence of anthropomorphic appearance on usage intention on online medical service robots (OMSRs): A neurophysiological study

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ABSTRACT

Online medical service robots (OMSRs) are becoming increasingly important in the medical industry, and their design has become a highly focused issue. This study investigated the neuroeconomics underlying the formation of usage intention, specifically evaluating the impact of anthropomorphic appearance and age on users' intentions to use OMSRs. Event-related potentials were used to analyze electroencephalography signals recorded from participants. This study found that OMSRs with a low anthropomorphic appearance induced larger P200 and P300 amplitudes, resulting in increased attentional resources compared to OMSRs with a moderate or high anthropomorphic appearance. OMSRs with moderate anthropomorphic appearances captured more attention and elicited larger P200 and P300 than those with high anthropomorphic appearances. Regarding age characteristics, OMSRs with senior features attracted more attention and induced larger P200 and P300 amplitudes. In terms of usage intention, compared to the others, users demonstrate a stronger usage intention towards the low anthropomorphism of OMSRs. Additionally, compared to the senior ones, users also exhibit a stronger usage intention toward a young appearance of OMSRs. These findings provide valuable insights for robot designers and practitioners to improve the appearance of OMSRs.

1. Introduction

With the advances in robotics technology, service robots have become increasingly common. For instance, for medical advice to patients [1,2], chat robots and virtual assistants provide banking services, while embedded service robots (such as Nao and Pepper) provide information and room services [3,4]. Simultaneously, with the rapid development of internet technology, the form of medical services has changed. In particular, since the outbreak of the COVID-19 pandemic in 2020, there has been a global rethinking of the form of medical services. Online medical services, as one such form, have been progressively accepted and utilized due to their efficiency, convenience, and time-saving attributes. Combined with the above, research on anthropomorphic robots has been extensively conducted in many fields but has not been subdivided into research on online medical service robots (OMSRs) with different degrees of anthropomorphic appearance. Previous research has shown that humanoid robots such as Pepper can improve human-robot

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interactions and facilitate consumer trust and acceptance [5,6]. Thus, this bolsters their usage intentions. Therefore, this study aimed to explore the effect of the anthropomorphic appearance of OMSRs on users' usage intentions and provide a reference for OMSR design.

Currently, robots are becoming ever more prevalent in medical services [7–9]. These robots perform a wide range of tasks, including electrophysiology sensing [8], robotic technology in foot and ankle surgery [10], and prosthetic tasks [9]. With the development of wireless networks and devices, medical robots have transitioned to OMSRs. OMSRs can collect and analyze users' medical records and symptoms and provide users with relevant medical information and diagnostic opinions. In terms of human-robot interactions, Duffy pointed out that robots need to have certain human-like traits, including appearance and behavior [11]. Research has been conducted on the appearance of service robots interacting with humans [12,13], where the level of anthropomorphic appearance can affect consumer responses [14]. Although the anthropomorphic appearance of service robots has a strong negative effect on consumers' usage intentions [15], research shows that human-like robots are more popular than animal-like robots [16,17]. This has led to the development of humanoid robots with human facial expressions and voices. However, some studies suggest that robots with lower human-likeness levels generate relatively more positive attitudes [18]; the more robots become like humans, the stranger and the more incomprehensible they become [19]. Although humanoid service robots appear to affect user perceptions of their interactions with them [20], it is currently unclear whether these increase or decrease their willingness to interact with them. Research has also shown that medical service robots can elicit emotional responses from users, such as attachment, anger, sadness, and even rejection [20]. Previous studies have demonstrated that the role of anthropomorphism (human likeness) can affect customer satisfaction with robots [21], with some researchers indicating that a pessimistic attitude towards humanoid service robots [22,23] and humanoid robots can elicit eeriness from users [24]. However, some studies have indicated that robots with human faces are better than faceless vending machines at interacting with people [25]. Through anthropomorphization, the integration of humanoid features can affect users' perceptions of robots [20]. Humans attribute their basic characteristics to robots to understand unpredictable behaviors such as emotions or rational thinking [26,27]. In the current field of medical service robots, limited research has been conducted on their anthropomorphized appearances in the context of network platforms. Furthermore, this study explored the impact of usage intention on the age features of a highly anthropomorphic appearance. Therefore, this study aims to fill this gap in the research on the anthropomorphic appearance of OMSRs.

To assess the appearance of anthropomorphic robots towards user usage intentions, researchers predominantly rely on the Technology Acceptance Model (TAM) [28] and the modified Unified Theory of Acceptance and Use of Technology (UTAUT) [29]. The TAM predicts user behavior towards information technology based on the theory of rational behavior and information system use [30]. Researchers evaluated the impact of a veterinary consultation chatbot on user intention to use it by modifying the TAM [31]. In contrast, the UTAUT model is an integrative model used to predict user willingness to adopt new technology. Liu used a modified UTAUT model to explore the impact of a robot's appearance on user intentions [32]. These research methods are based on questionnaire surveys that collect user opinions and feedback to evaluate their intention to use robots. For example, Estriegana used a technology acceptance model to assess students' acceptance of virtual labs and actual work [33], whereas Hu used a technology acceptance model to evaluate bank users' intentions towards fintech services [34].

In addition to the existing TAM and UTAUT, neuroergonomic methods can be employed to understand user behavior better. Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) are the most commonly used physiological techniques in neuroergonomics. Neuroergonomics can be used to correlate user preferences [35] and choices [36]. EEG measurements allow real-time monitoring of brain activity without an appreciable time delay [37]. Event-related potentials (ERPs) are neural responses linked to specific cognitive events and can be extracted from EEG using averaging techniques [38]. ERPs provide insights into the brain's affective processes, behavioral intention, and decision-making processes [38–40]. Therefore, current research on emotional processing using ERPs in the human brain is receiving increasing attention [41].

Since neuroergonomic approaches can facilitate users' cognitive processing, we used a questionnaire to explore the effects of anthropomorphic OMSRs on usage intention and ERP to investigate users' brain responses while viewing the OMSRs. Numerous studies have shown that user behavior is related to ERPs [39,42,43]. For instance, Ozkara demonstrated a relationship between ERPs and purchasing intention [42]. Existing ERP research on user behavior has identified two main ERP components: P200 and P300 [40,44,45]. The role of P200 has been widely reported in previous research on the relationship between behavior and attention [46]. For example, in a study on the attractiveness evaluation of anthropomorphic application icons, Cao et al. found that anthropomorphic application icons induced a larger P200 than non-anthropomorphic ones [45]. P3, a widely used 'cognitive' ERP, has been observed in several studies on attention and purchasing intention [37,39]. For instance, Ding et al. used the ERP method to investigate the behavioral intention process when participants browsed different smartphone designs based on brand and price. They found that pictures evoked an enhanced P300 to inhibit button clicking when the participants had no behavioral intention [40,47].

This study explores users' usage intention to OMSRs with different degrees of anthropomorphic appearance and age characteristics and investigates users' cognitive responses to these robots. We employed questionnaire surveys and ERP methods to better assess user usage intentions to different OMSRs and related brain mechanisms to achieve this goal. The findings of this study are important for OMSRs designers to gain a deeper understanding of the impact of the degree of anthropomorphic appearance and highly anthropomorphic age features on user usage intention.

2. Research measure

2.1. Participants

A prior calculation was conducted to determine the required sample size using G*Power [48], and a minimum sample size of 20 was needed to detect a large effect size ($f = 0.4$) in a two-way repeated measures analysis of variance (ANOVA) with a recommended statistical power β of 95% and error probability of 0.05. Thirty students with different majors at Anhui Polytechnic University, including 17 boys and 13 girls, were recruited through the WeChat platform. Before the experiment, the participants had not participated in the appearance study of OMSRs. All participants were right-handed with normal or corrected vision, normal hearing, and no history of brain trauma or genetic diseases. During an experiment involving EEG recordings from a boy, the amplifier experienced a power issue, which interrupted the experiment and resulted in the loss of EEG data. Therefore, EEG data were collected from only 29 participants (16 boys and 13 girls), and questionnaires were collected from 30 participants. The age of the participants ranged from 19 to 28 years (mean (M) = 22.1 years, standard deviation (SD) = 2.468). The experimental site was located within the Foreign Language ERP Laboratory at Anhui Polytechnic University. The experiment began on December 2, 2022, and was completed on March 1, 2023. All participants signed an informed consent form before the experiment and received 50 yuan as remuneration.

2.2. Stimuli and apparatus

The experimental equipment employed was a BrainVision EEG system from Brain Products, which consists of hardware and software. The hardware included an HP computer, ACTi Champ amplifier (sampling rate: 50 KHz/channel, frequency bandwidth DC-20,000 Hz, common mode rejection ratio >100 dB), 64-channel wired wet elastic mesh EEG cap, GREENTEK medical conductive paste, Nuprep medical scrubbing paste, syringes, a ruler, and a marker pen.

Ten nontarget OMSRs pictures (Fig. 1) and three target flower pictures were used as the stimulus set. These images represented different levels of anthropomorphism and the highly anthropomorphic age characteristics of the OMSRs. The images used in the experiment were obtained from various sources, including Taobao and Visual China. The images were then processed using Photoshop software and each image was sized to 1920 × 1150 pixels. In addition, three flower images from Baidu Images were selected as target stimuli.

In the early stages of the experiment, a pre-survey of the degree of the anthropomorphic appearance of OMSRs was conducted. A questionnaire was devised to assess the degree of anthropomorphism in OMSRs and control the efficiency of anthropomorphism manipulation. The questionnaire included an independent variable of anthropomorphism using a Likert scale revised based on Mathur and Reichling [49]. The participants were asked to rate the extent to which the robot's appearance resembled that of a human using a 1–7 rating scale, with a higher number indicating a higher degree of anthropomorphism. A total of 87 students from Anhui Polytechnic University were surveyed, with one invalid sample resulting in 86 valid samples. The degree of anthropomorphic appearance of the 10 OMSRs was rated. Participants viewed 10 OMSR images and rated the degree of anthropomorphism of the robot's appearance using a 7-point scale. The results showed that the anthropomorphism ratings of the ten online medical robots were $M_1 = 3.66$, $M_2 = 4.07$, $M_3 = 4.85$, $M_4 = 4.93$, $M_5 = 6.17$, $M_6 = 6.24$, $M_7 = 6.01$, $M_8 = 6.26$, $M_9 = 6.22$, and $M_{10} = 5.92$. Based on the similarity of robot appearance, we divided the robot appearance into three categories from low to high: $M_L = 3.87$, $M_M = 4.89$, and $M_H = 6.14$. The results of the significance test showed that participants could assess robot appearance with different levels of anthropomorphism and that the anthropomorphism manipulation was effective ($p < 0.05$). Thus, M1 and M2 are low OMSRs, M3 and M4 are moderate OMSRs, and M5, M6, M7, M8, M9, and M10 are high OMSRs. We divided OMSRs' age into three groups: young, middle-aged, and elderly. Therefore, M5 and M8 belonged to the youth group, M6 and M9 belonged to the middle-aged group, and M7 and M10 belonged to the older group.

2.3. Procedure

The experiment was divided into two distinct stages: the former entailed an oddball experiment, while the latter involved a survey questionnaire concerning an individual's usage intention for OMSRs. To begin the oddball experiment paradigm in the first stage, all participants had to maintain their gaze fixed at the center of the screen, with their pupils positioned approximately 80 cm from the center of the display and maintaining a horizontal viewing angle of 4°. The experimenter presented the participants with the experimental process and tasks before the experiment began. The experiment started, and the participants underwent 12 practice trials

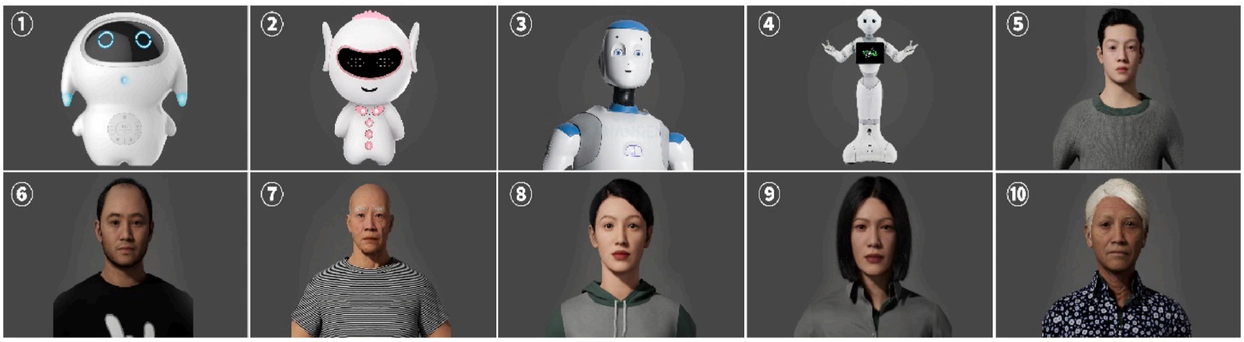

Fig. 1. Stimulating materials for online medical service robots.

to familiarize themselves with the experimental procedure and requirements. After completing the practice trials, participants entered the formal experiment and were required to remember the number of times the flower picture (target stimulus) appeared. The OMSR picture served as a non-target stimulus, and the “+” picture focused the participant’s attention, with no memory required for these pictures. The duration of each stimulus was 1000–1200 ms, and the order of the stimuli was random. Participants were allowed a period of rest to adjust to the state. The process for each trial is illustrated in Fig. 2. At the conclusion of the initial phase of the experiment, the participants were asked to rate their intention to use the OMSRs for six non-target stimuli. The usage intention was evaluated using three questions based on Agarwal and Karahanna’s [50] work: “I plan to use the OMSRs”, “I intend to continue using the OMSRs”, and “I expect to use the OMSRs in the future”.

2.4. EEG recording and analysis

EEG signals were continuously recorded using a NeuroScan EEG system (Neurosoft Labs Inc.) with 64 active Ag/AgCl electrodes (Fig. 3). Fig. 3 represents the 10–20 international system version, in which the relative distances between the scalp electrode points were 10% and 20%. This system used two reference lines: the sagittal and coronal lines. The electrodes were connected using a monopolar montage with FCz as the reference electrode, and the potential difference between each active electrode and the reference electrode was used as the respective potential value. To eliminate artifacts, a vertical electrooculogram (VEOG) and sometimes an electrocardiogram (ECG) were recorded alongside the ERP, and a horizontal electrooculogram (HEOG) was recorded to monitor eye movements. A conductive paste reduces skin-electrode resistance to less than 5 kΩ. The ActiCHamp amplifier (actiCAP, Brain Products GmbH, Germany) amplifies the EEG signal with a common mode rejection ratio (CMRR) ≥100 dB and a passband of 0.05 Hz–70 Hz, sampled at 1000 Hz. The BrainVision Recorder software (Brain Products GmbH, Germany) was used to record and store the EEG signals.

The offline analysis was performed in MATLAB (R2020b) using EEGLAB (version 2019.0), an open-source toolbox developed by Cancino and Delorme [51]. The EEG data of each participant were imported into EEGLAB, and after confirming the channel locations, the reference electrode was transformed from FCz to TP9 and TP10. The sampling rate was then reduced from 1000 Hz–500 Hz. A 0.1–30 Hz bandpass filter was applied to eliminate slow non-neuronal movements and 50/60 Hz circuit noise. After establishing a bin list based on different stimulus types (anthropomorphism and age), the EEG signal was time-locked at 500 ms before and 3000 ms after the onset of the target stimulus. The EEG signal time window was locked at −200 ms to 1000 ms after removing eye-movement artifacts using principal component analysis. The average ERP values were calculated for each channel and stimulus type, and all participants’ ERP data were then averaged.

2.5. Statistical analysis

Statistical analysis of ERPs and usage intention was conducted on the average amplitude values of endogenous factors using repeated measures/usage intention values with within-subject factors: the anthropomorphic appearance of OMSRs and sites. Additionally, to investigate the influence of ERP components and usage intention on the age features of highly anthropomorphic OMSRs, a two-factor repeated-measures ANOVA (within-subject factors: age features and location) was performed on the age features. Data analysis was performed using SPSS 22.0. If the assumption of sphericity was violated, the Greenhouse–Geisser correction was used to adjust for this violation. Statistical tests were performed at an alpha level of 0.05.

3. Result

3.1. Subjective questionnaire

The reliability and validity of the scale were tested using SPSS version 22.0. The results showed that Cronbach’s α values for the user’s usage intention towards OMSRs with anthropomorphic appearance and age were 0.790 and 0.895, respectively. The two factors of the model were analyzed using factor analysis. After rotation using the maximum variance method, the KOM values for usage intention with anthropomorphism and age were 0.654 and 0.608, respectively. The Bartlett sphericity test was significant at the 0.001 level, indicating good structural validity of the questionnaire.

Based on the repeated measures ANOVA conducted on the usage intention of OMSRs with varying levels of anthropomorphic appearance and different age features, the results showed a significant main effect of the robot’s anthropomorphic appearance and ages (anthropomorphism: F [2,52] = 11.881, $p < 0.001$, partial $\eta 2 = 0.291$; age: $F (2, 58) = 5.573$, $p = 0.006$, partial $\eta 2 = 0.161$).

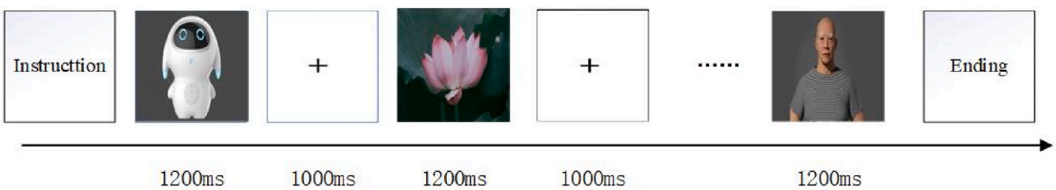

Fig. 2. Flowchart for electroencephalography (EEG) experiment with online medical service robots.

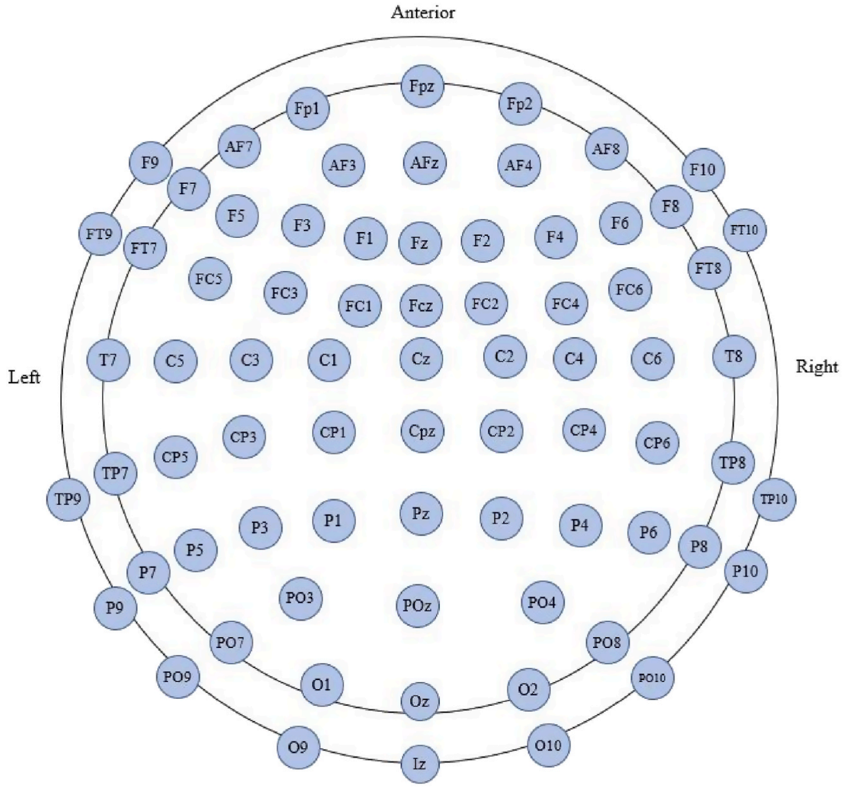

Fig. 3. The 10–20 international standardization navigation system.

Further pairwise comparisons revealed that a low anthropomorphic appearance had a significantly greater usage intention than a moderate anthropomorphic appearance (p = 0.001), and a low anthropomorphic appearance had a significantly greater usage intention than a high anthropomorphic appearance (p = 0.001]. There was no significant difference between moderate and high

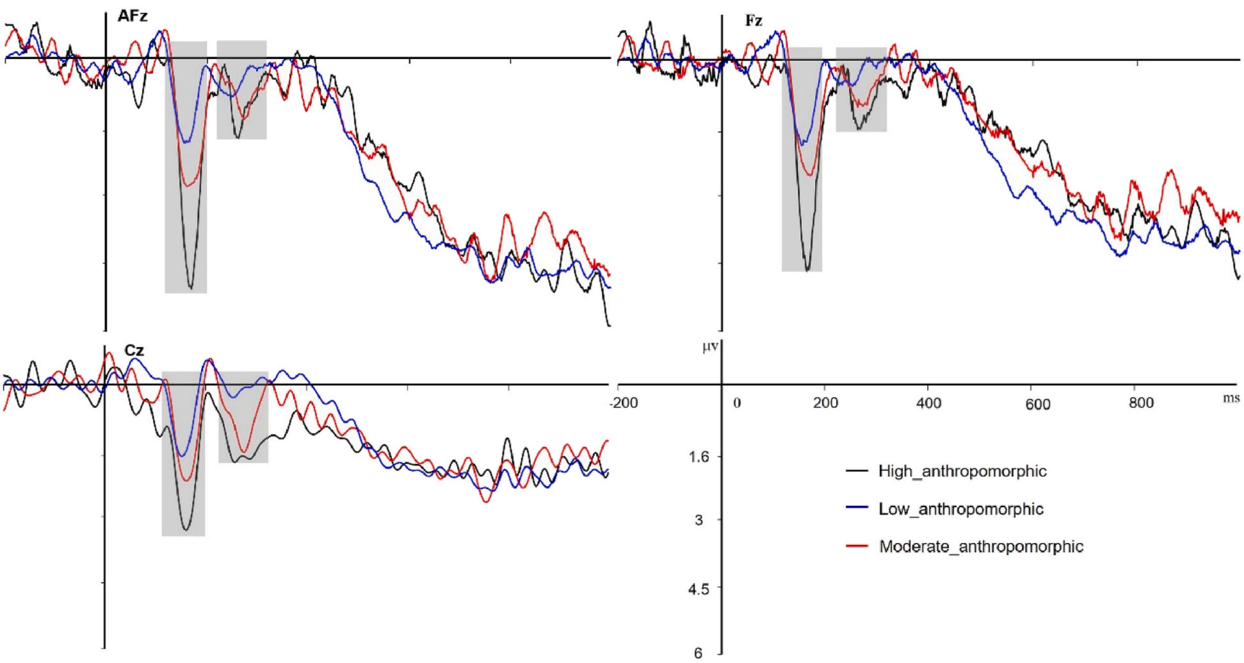

Fig. 4. The grand averaged waveform for online medical service robots' anthropomorphic appearance conditions.

anthropomorphic appearances ($p = 0.779$).

In addition, the pairwise comparison results showed that participants had a greater usage intention towards OMSRs with younger appearances than those with senior appearances ($p = 0.014$). However, compared to younger OMSRs, there was no significant difference in usage intention towards OMSRs with a middle-aged appearance ($p = 0.837$), and there was no significant difference between middle-aged and senior OMSRs ($p = 0.059$).

3.2. Electrophysiology

Based on visual inspection of the grand-averaged ERP waveforms (Fig. 4) and topographic maps (Fig. 5) of the degree of anthropomorphism, the P200 and P300 components were chosen for analysis. Similarly, the grand-averaged ERP waveforms and topographic maps of the age characteristics (more details see Figs. 10 and 11 in Appendix) were visually inspected for analysis. Fig. 4 shows the performance of OMSRs with low, moderate, and high anthropomorphism on the grand-averaged ERP waveforms at different electrodes. Blue, red, and black represent variations in waveform amplitude over time for participants observing low, moderate, and high anthropomorphic OMSRs, respectively. Fig. 5 shows the performances of low, moderate, and high anthropomorphic OMSRs on a topographic map at different time points. Other colors are used in the topographic map to represent the level of neural activity, with warmer colors closer to red indicating more active neural activity and cooler colors closer to blue indicating less neural activity. The 12 electrodes were divided into four anatomical subgroups: anterior-frontal (AF3, AFz, and AF4), frontal (F3, Fz, and F4), central (C3, Cz, and C4), and central-parietal (CP3, CPz, and CP4) groups. For the P200 and P300 components, this allowed for the analysis of anthropomorphism as a factor at level two (low anthropomorphic OMSRs' appearance, moderate anthropomorphic OMSR's appearance, and high anthropomorphic OMSR's appearance) and sites at three levels (anterior-frontal, frontal, and central groups). The P200 component was captured in the anterior frontal, frontal, and central 140–200 ms time windows. The P300 component was captured in the anterior frontal, frontal, and central 220–320 ms time windows.

3.2.1. P200 (140–200 ms)

For the anthropomorphic appearance of OMSRs, whether in the anterior-frontal, frontal, or central area, there was a significant main effect of OMSR's anthropomorphism (anterior-frontal: $F[1.598, 44.743] = 12.746$, $p < 0.001$, partial $\eta 2 = 0.313$; frontal: $F[2,56] = 8.658$, $p = 0.001$, partial $\eta 2 = 0.236$; central: $F[1.542, 43.186] = 12.571$, $p < 0.001$, partial $\eta 2 = 0.310$). There was no significant main effect of sites (anterior-frontal: $F[2,56] = 0.738$, $p = 0.482$, partial $\eta 2 = 0.026$; frontal: $F[2,56] = 0.014$, $p = 0.986$, partial $\eta 2 < 0.001$; central: $F[2,56] = 1.127$, $p = 0.331$, partial $\eta 2 = 0.039$). There was no significant interaction effect of OMSR's anthropomorphism*sites (anterior-frontal: $F[3.223, 90.249] = 1.403$, $p = 0.145$, partial $\eta 2 = 0.061$; frontal: $F[4112] = 8.658$, $p = 0.238$, partial $\eta 2 = 0.048$; central: $F[4112] = 0.325$, $p = 0.861$, partial $\eta 2 = 0.011$). The pair comparison results revealed that the low anthropomorphic appearance of OMSRs evoked a larger P200 amplitude than the high anthropomorphic appearance (anterior-frontal: $p = 0.001$; frontal: $p = 0.003$; central: $p = 0.001$), and the moderate anthropomorphic appearance induced a larger amplitude of P200 than the high anthropomorphic appearance (anterior-frontal: $p = 0.001$; central: $p = 0.007$) (Fig. 6, more details about P200 see Table 1 in Appendix).

Both in the anterior-frontal and central-parietal area, further research into the age characteristics of highly anthropomorphic OMSRs revealed a significant main effect of OMSRs' age characteristics (anterior-frontal: $F[2,56] = 6.520$, $p = 0.003$, partial $\eta 2 =$

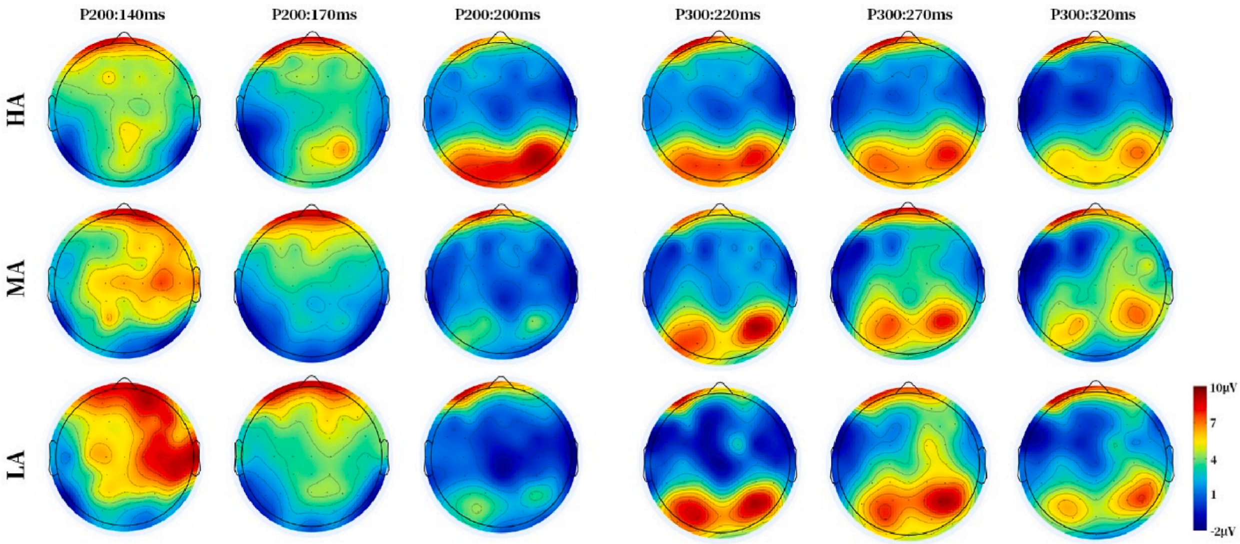

Fig. 5. The topographic maps of online medical service robots' anthropomorphic appearance conditions.
Note: "HA" represents highly anthropomorphism; "MA" represents moderate anthropomorphism; "LA" represents low anthropomorphism.

0.189; central-parietal: F [2,56] = 5.484, p = 0.007, partial η2 = 0.164). There were no significant main effects of sites (anterior-frontal: F [2,56] = 0.116, p = 0.891, partial η2 = 0.004; central-parietal: F [2,56] = 1.180, p = 0.315, partial η2 = 0.040) and interaction effects of OMSRs' ages*sites (anterior-frontal: F [2.207, 61.798] = 2.781, p = 0.065, partial η2 = 0.090; central-parietal: F [2.419, 67.720] = 2.088, p = 0.122, partial η2 = 0.069). The pair comparison results showed that the senior-appearance of OMSRs evoked a larger amplitude of P200 than the younger-appearance OMSRs (anterior frontal: p = 0.023; central-parietal: p = 0.008), and the senior-appearance OMSRs evoked a larger amplitude of P200 than the middle-aged-appearance OMSRs (anterior frontal: p = 0.009) (Fig. 7, more details about P200 see Table 2 in Appendix).

3.2.2. *P300 (220–320 ms)*

For the anthropomorphic appearance of OMSRs, both in the anterior-frontal and frontal area, there were no significant main effects of OMSRs' anthropomorphism (anterior-frontal: F [2,56] = 1.225, p = 0.302, partial η2 = 0.042; frontal: F [2,56] = 0.952, p = 0.392, partial η2 = 0.033) and sites (anterior-frontal: F [2,56] = 2.417, p = 0.098, partial η2 = 0.079; frontal: F [1.639, 45.890] = 2.933, p = 0.061, partial η2 = 0.095). There was no significant interaction effect of OMSRs anthropomorphism*sites (anterior-frontal: F [2.498, 69.950] = 2.003, p = 0.132, partial η2 = 0.067; frontal: F [2.450, 68.609] = 1.514, p = 0.203, partial η2 = 0.051; central: F [2.501, 70.039] = 0.727, p = 0.516, partial η2 = 0.025). For the central area, there was a significant main effect of OMSRs' anthropomorphism (central: F [2,56] = 6.337, p = 0.003, partial η2 = 0.185) and sites (central: F [2,56] = 3.587, p = 0.034, partial η2 = 0.114). For the central area, the pair comparison results revealed that the low anthropomorphic appearance of OMSRs evoked a larger P300 amplitude than the high anthropomorphic appearance (central: p = 0.017), and the moderate anthropomorphic appearance induced a larger amplitude of P300 than the high anthropomorphic appearance (central: p = 0.022) (Fig. 8, more details see Table 3 in Appendix).

Therefore, further research on the age characteristics of highly anthropomorphic OMSRs is required. There was a significant main effect of different OMSRs' age characteristics (anterior-frontal: F [2,56] = 5.645, p = 0.006, partial η2 = 0.168) and interaction effect of the OMSRs' age*sites (anterior-frontal: F [2.441,68.353] = 3.126, p = 0.041, partial η2 = 0.100). The simple effect analysis showed that for the channel AF3 condition, the seniors for OMSRs enhanced the amplitude of the P300 compared to the middle-aged (p = 0.001). The simple effect analysis showed that seniors for OMSRs evoked a larger amplitude of P300 than the younger (AFz channel condition: p = 0.022; AF4 channel condition: p = 0.004), and seniors for OMSRs evoked a larger amplitude of P300 than the middle-aged (AFz channel condition: p = 0.014; AF4 channel condition: p = 0.022) (Fig. 9, more details see Table 4 in Appendix).

4. Discussion

Appearance is the external manifestation of product information and users' most direct and stable cognitive object [53]. A virtual agent's emotional facial expression can affect its sense of touch perception [54]. The moderately anthropomorphic appearance of a robot can improve user perception [55] and stimulate a stronger desire for interaction [56]. In this study, ERP experiments were conducted to explore the neural mechanism of users toward OMSRs. In addition, Mathur and Reichling's five-point Likert scale was employed to gather user evaluations of usage intentions for OMSRs. 4.1 Impact of the appearance of OMSRs on usage intention.

The results indicated that users preferred OMSRs with a low degree of anthropomorphism over the other two types of anthropomorphic appearances. Based on Mathur and Reichling's findings [49], trust follows an "uncanny valley" curve, and higher degrees of anthropomorphism did not necessarily lead to stronger user trust. Therefore, highly and moderately anthropomorphic OMSRs with anthropomorphic appearance may cause discomfort and mistrust among users, leading to decreased usage intention. Further investigation into the age characteristics of highly anthropomorphic appearances showed that users preferred OMSRs with younger appearances to those with senior appearances. One reasonable explanation is that college students, as a young group, are more likely to feel closeness and empathy with young-looking OMSRs, based on self-image congruence theory [57,58]. Previous research has shown that consumers are more likely to purchase products and brands perceived as similar or complementary to their self-image [52]. Therefore, the usage intention for OMSRs with younger appearances is higher than that for OMSRs with senior appearances.

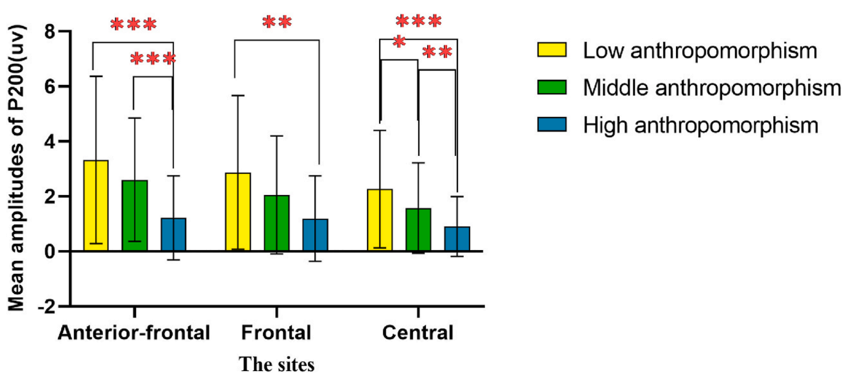

Fig. 6. Mean amplitudes of P200 in the anterior-frontal, frontal, and central sites.
Note: "***" represents P ≤ 0.001; "**" represents 0.001 ≤ P ≤ 0.01; "*" represents 0.01 ≤ P ≤ 0.05.

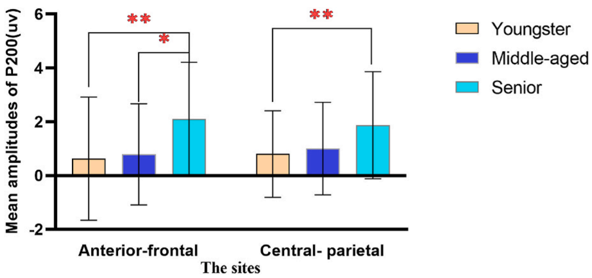

Fig. 7. Mean amplitudes of P200 in the anterior-frontal and central-parietal sites.

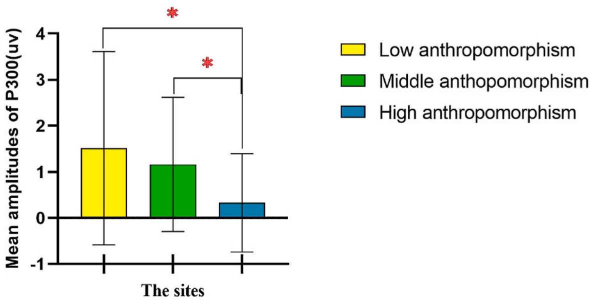

Fig. 8. Mean amplitudes of P300 in the central site.

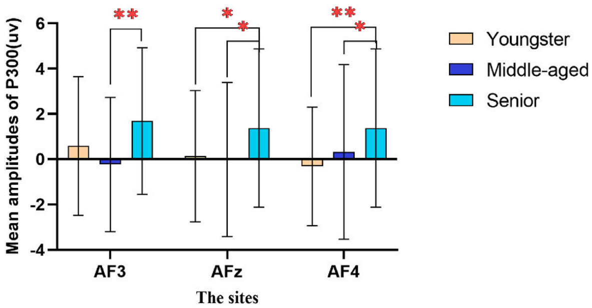

Fig. 9. Mean amplitudes of P300 in the anterior-frontal site.

4.1. Impact of the appearance of OMSRs on ERP components

4.1.1. P200

The P200 has a positive potential, with a latency of approximately 200 ms. It reflects the early stage of exogenous "attention capture" [59]. The results of this study suggest that compared to those with moderate and high anthropomorphism, users need to invest more cognitive resources in OMSRs with low anthropomorphism to conduct information processing. Similarly, users must invest more cognitive resources in OMSRs with moderate anthropomorphism than those with high anthropomorphism. Guo demonstrated that compared with non-preferred humanoid robots, preferred humanoid robots induced positive effects and gained more attention [60]. Therefore, compared with high and moderate anthropomorphic OMSRs, users prefer low anthropomorphic robots, which results in the usage intention of low anthropomorphic ones; compared with high anthropomorphic OMSRs, users prefer moderate anthropomorphic ones. One speculative interpretation is that OMSRs with low anthropomorphism may appear more comfortable than those with moderate and high anthropomorphism, and moderate anthropomorphic OMSRs might look closer to those with high anthropomorphism. Furthermore, in exploring the age characteristics of high anthropomorphism, statistical results showed that the amplitude of P200 evoked by the senior appearance of OMSRs was significantly higher than that evoked by the younger and middle-aged appearances. Our study showed that OMSRs with senior appearances were allocated more attention than those with middle-aged or younger appearances. One reasonable explanation is that OMSRs with a senior appearance may appear trustworthy because they attract more visual attention. An increased P200 amplitude distribution is associated with brain information processing [61]. Users must invest more cognitive resources in OMSRs with senior appearances.

4.1.2. P300

P300 has a positive potential with a latency of approximately 300 ms, reflecting attention allocation to task-relevant stimuli and behavioral intentions [40,62]. Research results showed that the P300 amplitude evoked by the low anthropomorphic appearance was significantly higher than that of a high anthropomorphic appearance, and the P300 amplitude evoked by OMSRs with a moderate anthropomorphic appearance was also significantly higher than that of a high anthropomorphic appearance. The above results showed that OMSRs with low and moderate anthropomorphic appearances attracted more attention than OMSRs with high anthropomorphic appearances. Hence, when a user sees low and moderate anthropomorphism in OMSRs, the user needs to allocate more resources for information processing. Further investigation of age-related features under high anthropomorphism revealed that the P300 amplitude evoked by the senior appearance of OMSRs was significantly higher than that evoked by younger or middle-aged appearance. The results of this study suggest that the senior appearance of OMSRs allocates more attentional resources to users. Previous research has confirmed that an increased P300 may indicate that further processing in attention is oriented toward user preference [63]. According to our research findings, although the senior appearance of OMSRs has the advantage of attracting attentional resources, their usage intention is not as high as that of OSMRRs with a younger appearance. One possible explanation is that the participants in this study were all young college students. According to self-image congruence theory [57], although they were more inclined to pay attention to OMSRs with a senior appearance in terms of allocating attention resources, under the theory's premise, they still showed a higher intention to use OMSRs with the same age appearance. This aspect warrants further exploration and verification in future studies.

5. Conclusion

This study primarily investigated users' usage intention and neural responses towards OMSRs with different degree of anthropomorphic appearance and age variations. The first conclusion is that, in terms of usage intention, users are more inclined to use the OMSRs with a low-level anthropomorphism and a younger appearance. The second conclusion is that, from a neuroergonomics perspective, the low-level anthropomorphism of OMSRs attracts most of the user's attentional resources during the recognition process; the moderate anthropomorphism of OMSRs captures more attention than the high anthropomorphism. The third conclusion is that users tend to devote more attention to the senior appearance of OMSRs.

This study's theoretical contribution is to reveal users' usage intention to different OMSRs and their brain cognitive response during the observation process. By utilizing survey questionnaires and EEG recordings, researchers can gain insights into users' intention to OMSRs and explore users' attention allocation through the EEG analysis. This study has certain limitations. The sample size for the EEG experiment was relatively small. Future research should expand the sample size to include participants from different age groups to explore the impact of age on OMSRs.

Ethics approval

The study protocol was approved in advance by the Institute of Neuroscience and Cognitive Psychology of Anhui Polytechnic University (No. AHPU-SEM-2023-02). All participants provided informed consent to participate in the study.

Data availability statement

The data that support the findings of this study are available at https://pan.baidu.com/s/1lRR4VMcKDKSa-I098IZb9A with extraction code: 0000.

CRediT authorship contribution statement

Yi Ding: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Funding acquisition, Conceptualization. **Ran Guo:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Muhammad Bilal:** Validation, Methodology. **Vincent G. Duffy:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare no competing interest. This work is supported by Anhui Provincial Natural Science Foundation (No. 2308085MG228), the Quality Engineering Project of Anhui Polytechnic University (No. 2021tszy02, 2021lzyybj01, 2021jyxm51), and the Scientific Research Project of Anhui Universities (No. 2023AH030023, 2023AH050925, 2023AH050934).

APPENDIX

Table 1
The anthropomorphic ANOVA results of P200.

Site	LA		MA		HA		F	η^2
	M	SD	M	SD	M	SD		
Anterior-frontal	9.958	9.128	7.817	6.730	3.654	4.580	12.746***	0.313
frontal	8.607	8.368	6.144	6.436	3.567	4.658	8.658**	0.236
central	6.778	6.408	4.720	4.944	2.708	3.258	12.571***	0.310

Note: "***" represents $P \leq 0.001$; "**" represents $0.001 \leq P \leq 0.01$; "*" represents $0.01 \leq P \leq 0.05$; "HA" represents highly anthropomorphism; "MA" represents moderate anthropomorphism; "LA" represents low anthropomorphism.

Table 2
The age ANOVA results of P200.

Site	Y		M		S		F	η^2
	M	SD	M	SD	M	SD		
Anterior-frontal	1.887	6.862	2.374	5.638	6.283	6.341	6.520**	0.189
Frontal	1.725	7.152	2.700	5.591	4.948	7.478	1.864	0.062
Central- parietal	2.403	4.830	3.012	5.164	5.628	5.971	5.484**	0.164

Note: "Y" represents younger-appearance; "M" represents middle-aged-appearance; "S" represents senior-appearance.

Table 3
The anthropomorphic ANOVA results of P300.

Site	LA		MA		HA		F	η^2
	M	SD	M	SD	M	SD		
Anterior-frontal	3.053	9.485	3.451	9.577	1.562	8.096	1.225	0.042
Frontal	2.830	8.795	2.681	8.692	1.280	7.720	0.952	0.033
central	4.540	6.290	3.481	4.370	0.983	3.200	6.337**	0.185

Table 4
The age ANOVA results of P300.

Site	Y		M		S		F	η^2
	M	SD	M	SD	M	SD		
Anterior-frontal	0.411	8.181	0.081	9.891	4.574	9.726	5.645**	0.168
Frontal	−0.506	6.837	−0.217	9.038	2.012	9.338	1.329	0.045
Central- parietal	1.970	4.299	2.019	5.073	4.855	7.476	2.631	0.086

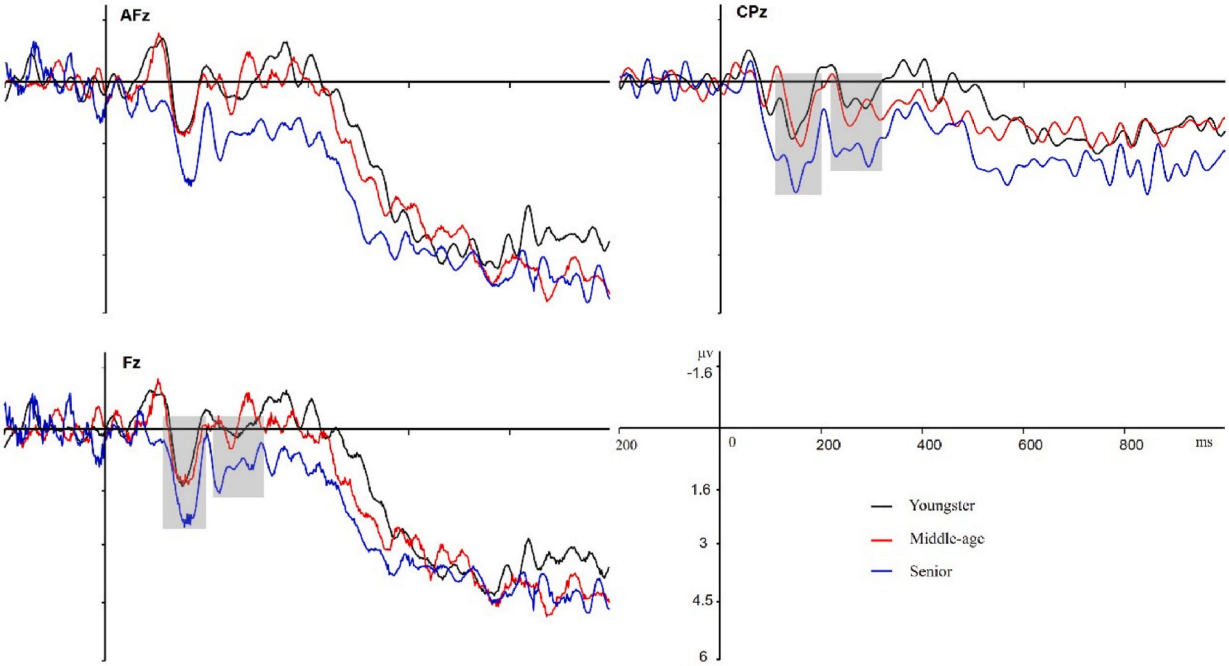

Fig. 10. The grand averaged waveform for OMSRs anthropomorphic appearance conditions.

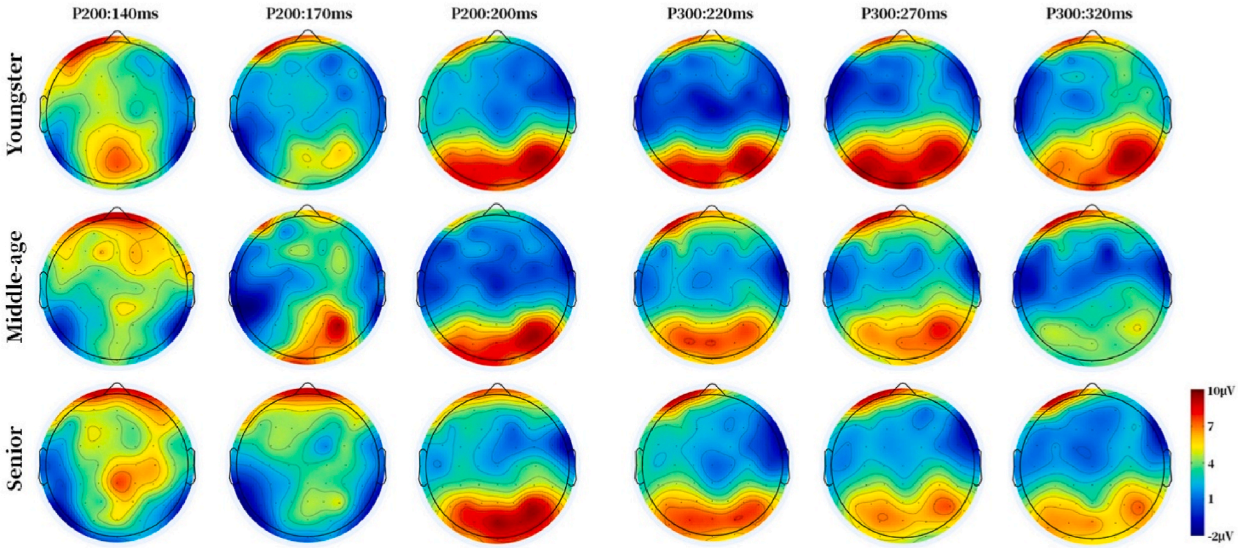

Fig. 11. The topographic maps of OMSRs anthropomorphic appearance conditions.

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