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Research article

The individual difference of motor imagery ability evoked by visual stimulus and its personality manifestation

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ABSTRACT

Motor imagery has been commonly studied as a means of motor rehabilitation but, the individual differences limit its practical application. Visually evoked motor imagery has been widely highlighted by researchers because of its vivid stimulus. However, this modality is still not applicable to all persons. In this study, we studied the different performances of the visually evoked motor imagery between subjects and tried to explore the personality manifestation which can result in this performance. We found that conscientiousness and openness have negative connections with the performance of visually evoked motor imagery. To compare with spontaneous motor imagery, the visually evoked motor imagery reflects less personality difference between subjects with good and bad performances on motor imagery. This indicate that visually stimulus may increase the pervasive application of motor imagery. This study may provide benefits to predict the rehabilitation effect and to rapidly select the suitable motor rehabilitation methods.

1. Introduction

Brain computer interface (BCI) is a communication path that can bypass the passageway of brain and muscle and realize the information exchange between the brain and external devices [1]. It has contributed to several fields, including rehabilitation [2], physical disability assistance [3], entertainment [4], neuroergonomics, aerospace and intelligence traffic system [5]. The brain activities collected in a BCI system can be categorized as magnetoencephalogram (MEG), electrocorticogram (ECoG), functional magnetic resonance imaging (fMRI), and electroencephalography (EEG), among others. Due to its non-invasive measurement and low cost, EEG has been widely used in BCI systems.

Many different paradigms have been developed to implement a BCI system. They can be categorized based on the patterns of brain activity [6]. The common patterns are visually evoked potential (VEP) [7,8], P300 [9] and slow cortical potential (SCP) [10]. These patterns are often generated under external visual and/or auditory stimuli. Thus, these BCI paradigms are vivid. Another brain pattern that could be suitable for implementing a BCI is event-related desynchronization and/or synchronization (ERD/ERS) [11,12] which can be evoked by motor imagery (MI), execution or observation [13,14]. MI is the imagination of movement without muscle activity, spontaneously. The brain areas which are responsible for sensorimotor function, sensorimotor cortex [15], primary motor cortex [16]

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and premotor cortex [17] can be activated during MI as the similar manner to motor execution. Thus, MI, motor observation and motor execution share similar neural mechanism, neural plasticity [18]. Therefore, based on this mechanism, MI is a very appropriate way of motor rehabilitation for patients after motor system damage. However, MI's performance relies on the participants' ability of the imagination to create vivid motor images. This differs greatly among subjects to compare with other BCI paradigms above. Moreover, MI's performance is limited by mental states [1,19,20]. Hence, lots of subjects cannot generate classifiable brain signals during MI tasks [21], and then to limit the applicability of MI in rehabilitation [19]. To conclude, spontaneous MI can not be served as a reliable rehabilitation way for all patients with motor system damage.

To improve the vividness of MI paradigms, many researchers have made many attempts. Moriuchi combined MI and action observation to study the vividness of MI [22]. The results indicate that observation information can promote the MI quality by affecting the corticospinal excitability. Saeki applied functional electrical stimulation and a visual stimulus to evoke MI [23]. They report that visual stimulus can affect the sense of agency and then to increase the MI performance. Lorey indicated that vivid MI has a relationship with an activation outcome of neural computation within motor areas [20]. Moreover, the hypothesis about the association between the increased perceived imagery vividness and brain activation on putamen, the premotor cortex, the posterior parietal cortex, the primary motor cortex, the somatosensory cortex, and the cerebellum is proved by Sakamoto. They indicate that the combine of observation and imagery on an action can enhance corticospinal excitability [24]. Ono states that Daily training with visual feedback induces more robust ERD than the no feedback training [25]. Zabick reports that spatial patterns of neural activity in the motor area reflect the vividness of an individual's imagination [26]. They demonstrate that the vividness of the motor imagery is related to the action specificity of neural activation pattern in left premotor cortex and right superior parietal lobe. Imagined action accompanied by higher vividness rating is significantly more distinguishable on these areas. Furthermore, virtual reality has been applied to further improve vividness [27–29], and then further enhance ERD during MI [30]. In our previous studies, we have applied visual and auditory stimuli to improve MI performance [1,31]. The results demonstrate the improved MI performance by these stimuli. Thus, visual stimulus is considered as a promising way to improve MI performance.

Therefore, visually evoked MI has been widely studied in rehabilitation [32,33] with the aim to improve the MI ability. However after the onset of neurological disorder, many patients experience the decrease in cognitive and/or motor ability [34]. This can further affect the MI performance of patients. Therefore, for early rehabilitation, the prediction of MI ability is crucial. Many researches try to find the way to predict the MI performance. Ahn reveals that when considering MI, low-performance individuals have a less-developed brain function network. Moreover, they state that the psychological and physiological states of individuals underlie the MI performance variation [19]. Jeunet tried to explore the relationships between the participant's BCI performance and personality, but did not identify a strong correlation [35]. Leeuwis studied the effects of many factors including personality, affinity for technology, and motivation, and discloses that the personality factors of orderliness and autonomy are the important factors for motor imagery performance [36]. Zapała reports the correlations between the information transmission rate of an MI-BCI system and endurance and perseveration [37]. Mladenović studied the influence of feedback emotion bias and personality on MI performance and indicates that the interactions between bias and workload, anxiety, and self-control can affect MI performance [38].

These researches above prove that the personality factors are related to the spontaneous MI's ability. However, to our best knowledge, the effects of personality factors on visually evoked MI performance remain unclear. Therefore, based on these, it is hypothesis that the performance of visually evoked MI is connected with personality factors. Motor function damage on upper and lower limbs is the common clinical manifestations after nervous system disease, such as stroke. Moreover, the brain areas related to unilateral leg movement focuses on the central area [1]. Therefore, unilateral leg MI is hard to generate classifiable brain signals to compare with

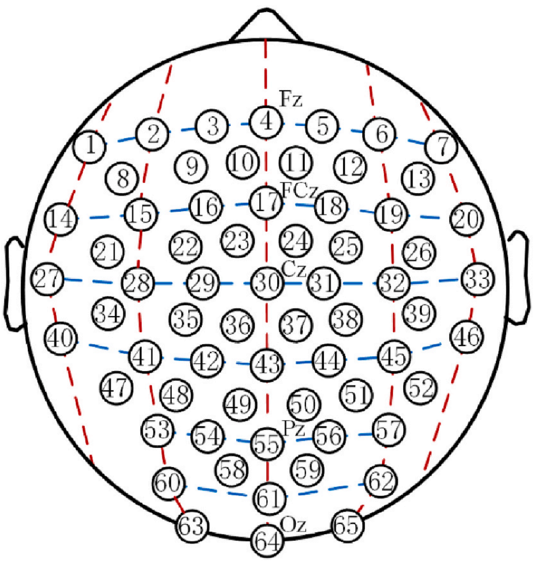

Fig. 1. The montage of EEG electrodes.

other parts of body, and then affects the motor rehabilitation of leg movement [31,39]. Thus, in this study, with the aim to explore the personality manifestation of visually evoked MI's performances, the differences of unilateral leg MI ability and personality between subjects are analyzed. The results of this study indicate that openness and conscientiousness may contribute to the performance of visually evoked MI. This study may provide benefits to predict the rehabilitation effect and to rapidly select the suitable motor rehabilitation methods, which could be favorable during the early stages of recovery from motor system damage.

2. Materials and methods

2.1. Participants

Thirty right-handed subjects (28 males and 2 females, MAge = 23.08 years, SDAge = 1.98 years) with normal motor ability and without injury or any other disease were included in this experiment. Half of the subjects had rich MI experience. They were good at MI and selected from the subjects of our previous studies [1,31]. The other subjects had not experienced MI previously.

2.2. Recordings

EEG data were collected by using 65 Ag–AgCl active electrodes with a g.HIamp EEG collection system (g.tec Inc., Austria). The electrodes included F5, F3, F1, Fz, FFC5h, FFC3h, FFC1h, FC5, FC3, FC1, FCz, FCC5h, FCC3h, FCC1h, C5, C3, C1, Cz, F6, F4, F2, FFC6h, FFC4h, FFC2h, FC6, FC4, FC2, FCC6h, FCC4h, FCC2h, C6, C4, C2, CCP5h, CCP3h, CCP1h, CP5, CP3, CP1, CPz, CPP5h, CPP3h, CPP1h, P3, P1, Pz, CCP6h, CCP4h, CCP2h, CP6, CP4, CP2, CPP6h, CPP4h, CPP2h, P4, P2, PPO1h, PO3, POz, O1, Oz, PPO2h, PO4 and O2. The montage of electrodes has displayed in Fig. 1. The sampling rate was 1200 Hz. The electrodes were placed according to the international 10–5 system [40]. A unilateral earlobe and the frontal position (Fpz) were selected to be the reference and the ground of electrodes, respectively. During data collection, the hardware notch filter (48–52 Hz) and bass-pass filter (2–100 Hz) were applied to remove interference and noise. All active electrode impedances were kept below 30 kΩ during the experiment. The revised neuroticism extraversion openness personality inventory (NEO-PI-R), which was proposed by Costa and McCrae in 1992 [41], was applied to evaluate the subjects' personality based on five dimensions: openness, conscientiousness, extraversion, agreeableness and neuroticism. Every dimension has six sub-dimensions, as illustrated in Table 1. The NEO-PI-R comprises 240 questions, which can be answered by using a 5-point Likert scale: 1 indicates strong disagreement with the question and 5 denotes strong agreement with the question. All the subjects were required to answer the questionnaire honestly before the MI experiment. The scores of each dimension and sub-dimensions were calculated after questionnaire.

2.3. The experimental procedure

This study focuses on leg MI. The object-oriented visually evoked paradigm [1,31] and non-stimulus paradigm of MI were applied in this study for comparison. Before experiments, there was a half hour training section for all the subjects to be familiar with the experimental design. The visual stimulus was a kicking ball movement and lasted 1.7 s. It included a right or left leg extension and restoration movement in visual stimulus. The non-stimulus paradigm did not involve any stimuli. The imagery process of non-stimulus paradigm lasted for 3 s. The subjects were asked to execute kinesthetic unilateral leg MI in a dark and electrically shielded room during the two paradigms. They were comfortably seated in an armchair behind a computer screen during the experiments. The experimental trial started with a concentration reminder, namely a crosshair in the screen center that lasted for 2 s. Then, an arrowhead pointing to the right or left was shown for 1 s; it was the reminder of the following MI direction and was displayed in the screen center. Subsequently, the subjects were asked to execute the kinesthetic MI of the leg extension and restoration movement, accompanied by the object-oriented stimulus or non-stimulus. The paradigm and imagery direction were displayed in pseudorandom. The subjects could relax for 4 s after every trial and for 1 min after every five trials, to eliminate the effects from the previous paradigm and mental fatigue. Each run of the trials was consisted of 5 trials. Each subject should complete 60 trials for each paradigm. The instructions of the experimental paradigm and the display of the stimulus were both controlled by the psychophysics toolbox [42]. The experimental procedure of visually evoked MI is illustrated in Fig. 2.

Table 1
The five dimensions and their sub-dimensions.

Neuroticism (N)	Extraversion (E)	Openness (O)	Agreeableness (A)	Conscientiousness (C)
Anxiety (N1)	Warmth (E1)	Fantasy (O1)	Trust (A1)	Competence (C1)
Angry hostility (N2)	Gregariousness (E2)	Aesthetics (O2)	Straightforwardness (A2)	Order (C2)
Depression (N3)	Assertiveness (E3)	Feelings (O3)	Altruism (A3)	Dutifulness (C3)
Self-consciousness (N4)	Activity (E4)	Actions (O4)	Compliance (A4)	Achievement striving (C4)
Impulsiveness (N5)	Excitement seeking (E5)	Ideas (O5)	Modest (A5)	Self-discipline (C5)
Vulnerability (N6)	Positive emotions (E6)	Values (O6)	tender-mindedness (A6)	Deliberation (C6)

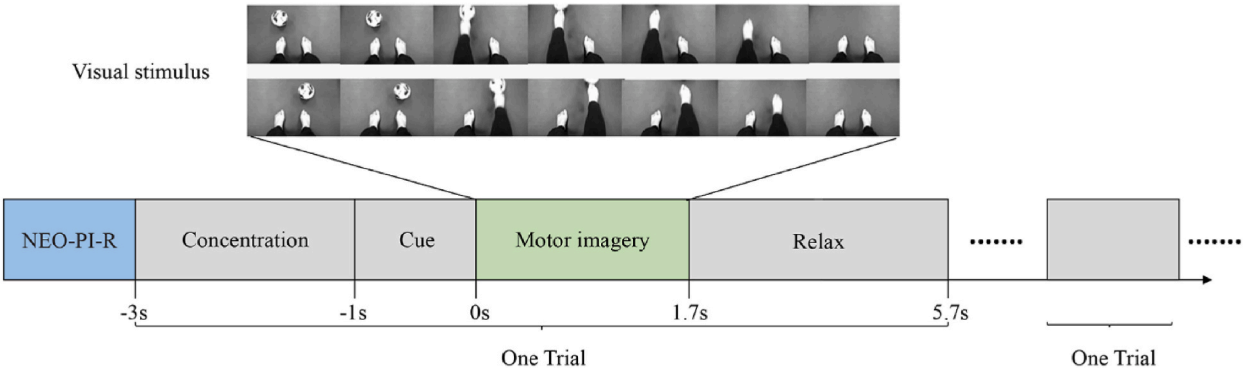

Fig. 2. The experimental procedure of the visually evoked motor imagery.

2.4. Analysis

To decrease the effect of the volume conduction, a surface Laplacian algorithm was employed on the EEG trials extracted from the EEG data flow. Then, the raw EEG data were processed by using empirical mode decomposition and regression algorithm [43] to remove ocular artifacts. After that, all the trials were bandpass filtered from 8 to 30 Hz. Then, the trials from the same subjects and direction were extracted and averaged. To evaluate the deactivation of the brain activity, the ERD, which indicates the inhibitory degree with respect to the baseline for the frequency band of interest, was calculated as described by Eq. (1). A negative ERD indicates inhibition of brain activity, and a positive ERD denotes enhanced brain activity. In this study, the concentration reminder was regarded as the baseline. The common spatial patterns (CSP) algorithm was employed to establish a spatial filter and to obtain features for MI classification. It decomposes multi-channel EEG data from two classes into different spatial patterns through simultaneously diagonalizing the EEG covariance matrices from the two classes. The CSP algorithm is detailed in Refs. [44,45]. To evaluate the differences between different subjects, the ERD, the scores of the five personality dimensions and the scores of 30 sub-dimensions were analyzed statistically. During statistical analysis, according the hypothesis testing method, the data were subjected to the Lilliefors test to determine whether they were normally distributed firstly. If they obeyed the normal distribution (OND), one-way analysis of variance (ANOVA) was applied to evaluate the differences between data. If they did not obey the normal distribution (N-OND), the Mann-Whitney test was applied to evaluate the differences between data. All the calculations were performed by using MATLAB (MathWorks, USA).

$$y(f_t, k) = \frac{\left(\frac{1}{p+1}\sum_{t=t_0}^{t_0+p} r_m^2(f_t, t, k) - \frac{1}{q+1}\sum_{t_b=t_{0b}}^{t_{0b}+q} r_b^2(f_t, t_b, k)\right)}{\frac{1}{q+1}\sum_{t_b=t_{0b}}^{t_{0b}+q} r_b^2(f_t, t_b, k)} \quad (1)$$

where, $y(f_t, k)$ is the ERD of brain activity, and $r_m(f_t, t, k)$ and $r_b(f_t, t_b, k)$ indicate the EEG amplitudes of the MI process and the baseline on the frequency band f_t of interest. p and q are the sampling numbers of MI and baseline, and k denotes the trial number.

Table 2
The MI classification results of the two groups.

No.	Object-oriented paradigm		Non-stimulus paradigm	
	Group 1	Group 2	Group 1	Group 2
1	0.634	0.517	0.546	0.562
2	0.646	0.543	0.486	0.503
3	0.735	0.537	0.513	0.500
4	0.654	0.555	0.558	0.461
5	0.620	0.547	0.489	0.486
6	0.769	0.570	0.698	0.461
7	0.608	0.583	0.568	0.532
8	0.603	0.517	0.853	0.474
9	0.684	0.589	0.495	0.542
10	0.609	0.527	0.482	0.441
11	0.654	0.559	0.513	0.565
12	0.624	0.550	0.562	0.598
13	0.674	0.545	0.579	0.548
14	0.673	0.549	0.703	0.557
15	0.649	0.514	0.544	0.505
Average (SD)	0.656 (0.045)	0.547 (0.022)	0.573 (0.100)	0.516 (0.045)

3. Results

The 65-channel EEG data were analyzed using the CSP algorithm. The extracted features from the single trials after spatial projection between the left and right leg MI were classified by LIBSVM with a radial basis function (RBF) [46]. 10-fold cross-validation was applied. Based on the classification results of leg MI evoked by visually object-oriented paradigm, the subjects were divided into two groups. The first group owned a better performance in classification results in object-oriented motor imagery than the second group. It should be noted that almost all the subjects in the first group were from the MI-experienced subjects, except subject 10. The classification results of the two groups are illustrated in Table 2. The topographical views of the average ERD on motor cortex across trials during right MI in the object-oriented visually evoked paradigm are illustrated in Fig. 3. The topographical views from S1 to S15 are the average results in every subject from group 1, and the others (S16–S30) are the average results in every subject from group 2. In this figure, the topographical views of AG1, AG2, and AG1–AG2 represent the average of group 1, the average of group 2, and the difference between the two groups, respectively. The classification accuracy of the two groups were applied for statistical analysis. The Lilliefors test indicated that the classification accuracy of the two groups were normally distributed in both two paradigms. The ANOVA was applied for statistical analysis. The factors were "groups" (group 1 vs. group 2) and "paradigms" (object-oriented and non-stimulus). There was a significant difference between the two groups ($F(1, 59) = 26.560$ $P < 0.01$ $\eta^2 = 0.322$) and between paradigms ($F(1, 59)$

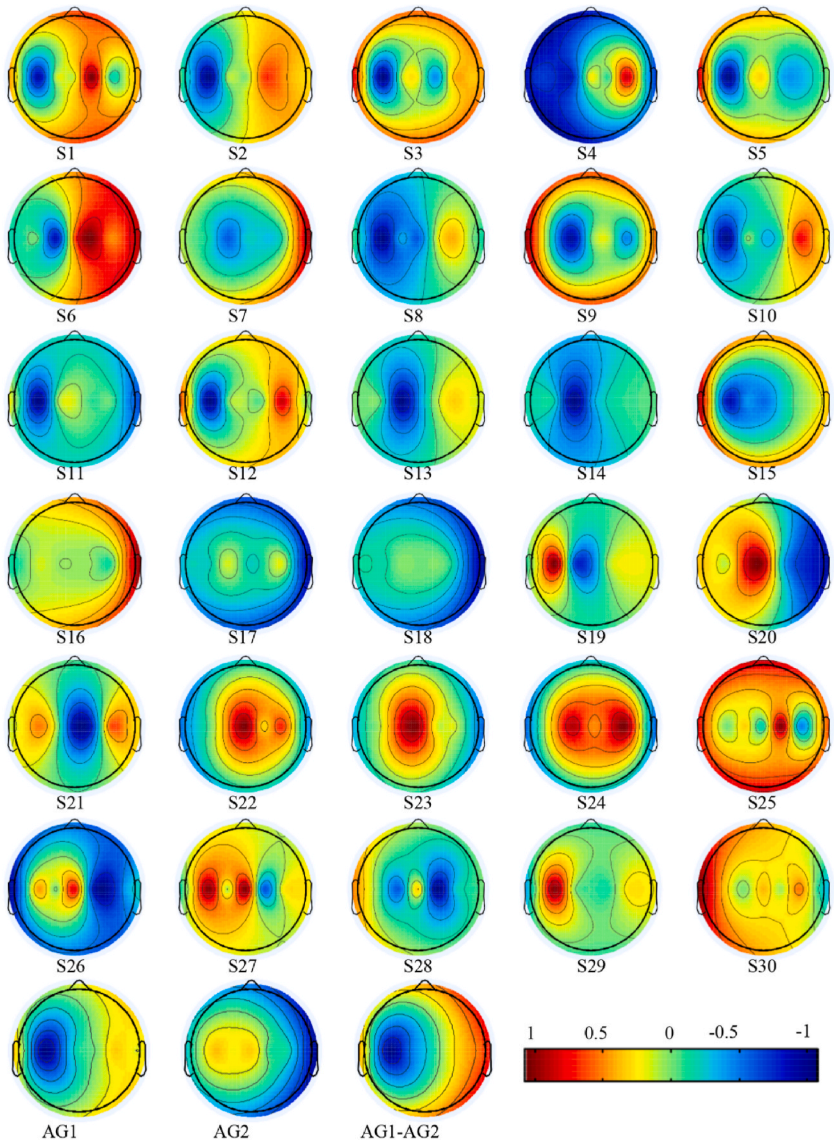

Fig. 3. The topographical views of the ERD across trials during MI of 30 subjects. S1 to S15 are the subjects from group 1, and S16 to S30 are the subjects from group 2 in the object-oriented visually evoked paradigm. The topographical views of AG1, AG2, and AG1–AG2 are the average of group 1, the average of group 2, and the difference between the two groups, respectively.

$= 12.663$ $P < 0.05$ $\eta^2 = 0.184$). These results indicate that there was a marked difference between the two groups, and the object-oriented visually evoked paradigm can promote the MI ability to compare with the non-stimulus paradigm.

To explore if there was an effect of personality effect on MI performance, statistical analysis was applied. The Lilliefors test indicated that all the scores of five dimensions from the two groups obeyed the normal distributions. The ANOVA was applied for statistical analysis. The factors were "groups" (group 1 vs. group 2) and "dimensionality" (N, E, O, A and C). The statistical results indicated that there was a significant difference between groups (F (1, 149) $= 3.907$ $P < 0.05$ $\eta^2 = 0.032$) and dimensionalities (F (4, 596) $= 16.286$ $P < 0.01$ $\eta^2 = 0.352$). This reveals that different dimensionality obeyed different distribution. Moreover, there was a significant "groups" × "dimensionality" interaction effect (F (4, 596) $= 2.792$ $P < 0.05$ $\eta^2 = 0.085$). It indicates that there is a different score distribution between groups. Bonferroni test was applied as the post-hoc test. The results are shown in Table 3. To further explore the differences between groups on the scores of five dimensions and the 30 sub-dimensions, ANOVA and Mann-Whitney test were applied. The statistical results on dimensions and sub-dimensions between groups are illustrated in Tables 4 and 5, respectively. The histogram of average NEO-PI-R scores for the 30 sub-dimensions are illustrated in Fig. 4. The results indicate that the group 1 had significantly lower scores than group 2 on openness and conscientiousness. On the sub-dimensions of the two dimensions above, group 1 obtained significantly lower scores than group 2 in ideas (O5), values (O6), dutifulness (C3), achievement striving (C4) and deliberation (C6). Therefore, these sub-dimensions may be the main factors that result in the significant differences between the groups. The scores of O5, O6, C3, C4 and C6 from the two groups were classified by LIBSVM with a radial basis function (RBF). The results of 10-fold cross-validation indicated that there was an average 83.3% classification accuracy with 13.1% standard deviation. This indicates that the personality sub-dimensions can be applied to predict the MI performance. Moreover, to explore the association between classification accuracy and NEO-PI-R's five dimensions on object-oriented visually evoked paradigm and no stimulus paradigm, the Pearson correlation coefficient was applied. The results are illustrated in Table 6. The results indicated that there was no significant correlation between NEO-PI-R's dimensions and classification accuracy on two kinds of paradigms.

4. Discussion

The previous study of MI-BCI suggested that the performance of MI-BCI depends on the classification algorithm, as well as the subject's personality [47]. In this study, the classification, statistical results and Fig. 3 from the two groups indicated that group 1 showed better performance than group 2 in visually evoked MI and non-stimulus MI. The statistical results also revealed that there were significant differences in openness and conscientiousness between two groups. Moreover, both openness and conscientiousness were negatively correlated with visually evoked MI performance. A previous study about mental rotation indicated that orderliness from the five factor personality inventory (FFPI) [48] was negatively associated with MI-BCI performance [36]. Openness was negatively correlated with orderliness [48] and tough-mindedness of the FFPI [49]. The functions of the dorsolateral prefrontal cortex and cognitive ability were positively related to openness [50]. Therefore, the results of this study indicate that the lower scores of openness can promote the performance of visually evoked MI but suppress the performance of mental rotation. Further, the dorsolateral prefrontal cortex may do not play an important role in visually evoked MI. Visually evoked MI comprises a vivid and concrete visual stimulus and mental imagery which refers to non-objective mental activity. The subjects in group 1, who showed better visually evoked MI performance, had significantly lower O5 and O6 scores compared with group 2. Thus, the subjects with lower scores on openness and better visually evoked MI performance may be obedient and easily affected by an external concrete stimulus. Furthermore, the other sub-dimensions of openness beyond O5 and O6 may have little impact on visually evoked MI performance. A previous study indicated that conscientiousness has negative correlation with creativity [51], which has a positive correlation with MI performance [52]. Therefore, the subjects with lower conscientiousness scores may have better creativity, and thus to promote their MI performance. Based on our study, the sub-dimensions, C3, C4, and C6 of conscientiousness could be negatively related to creativity. In this study, the results of Pearson correlation coefficient revealed no significant differences between NEO-PI-R's dimensions and classification accuracy. Thus, O5, O6, C3, C4 and C6 may be indirect factors that can affect the MI ability. Previous studies have revealed that other factors could also affect MI performance. Tension was reported to be negatively correlated with emotional stability from the FFPI, and positively correlated with neuroticism [35]. It also had a negative connection with MI performance during left and right hand imagery [35]. Self-reliance, which negatively contributed to extraversion [49] was believed to be related negatively to MI performance [36]. These studies indicate that extraversion and neuroticism are linked to MI performance. However, we did not identify these correlations in our study. Thus, a vivid and concrete visual stimulus may decrease the demand of the personality and increase the pervasive applications of MI.

Table 3
The post-hoc results of the scores on NEO-PI-R's five dimensions by Bonferroni test.

Dimension	Neuroticism	Extraversion	Openness	Agreeableness	Conscientiousness
Neuroticism	NA	$P = 0.016$*	$P = 0.001$*	$P = 0.004$*	$P = 0.006$*
Extraversion	$P = 0.016$*	NA	$P = 0.335$	$P = 0.631$	$P = 0.002$*
Openness	$P = 0.001$*	$P = 0.335$	NA	$P = 1.000$	$P = 0.992$
Agreeableness	$P = 0.004$*	$P = 0.631$	$P = 1.000$	NA	$P = 0.551$
Conscientiousness	$P = 0.006$*	$P = 0.002$*	$P = 0.992$	$P = 0.551$	NA

*Indicates significant difference at 0.05 level.

Table 4
The statistical results of the scores on NEO-PI-R's five dimensions.

Dimension	Lilliefors test of group 1	Lilliefors test of group 2	ANOVA
Neuroticism	OND	OND	F (1, 29) = 1.236 P = 0.277 η^2 = 0.049
Extraversion	OND	OND	F (1, 29) = 0.727 P = 0.402 η^2 = 0.029
Openness*	OND	OND	F (1, 29) = 8.512 P = 0.008 η^2 = 0.262
Agreeableness	OND	OND	F (1, 29) = 0.399 P = 0.533 η^2 = 0.016
Conscientiousness*	OND	OND	F (1, 29) = 7.794 P = 0.017 η^2 = 0.245

*Indicates significant difference at 0.05 level.

Table 5
The statistical results of the scores on NEO-PI-R's 30 sub-dimensions (SD).

N	SD	Group 1	Group 2	ANOVA	Mann-Whitney
1	N1	OND	OND	F (1, 29) = 3.187 P = 0.087 η^2 = 0.117	
2	N2	OND	OND	F (1, 29) = 0.716 P = 0.406 η^2 = 0.029	
3	N3	OND	OND	F (1, 29) = 0.170 P = 0.684 η^2 = 0.007	
4	N4	OND	OND	F (1, 29) = 0.099 P = 0.756 η^2 = 0.004	
5	N5	OND	OND	F (1, 29) = 1.009 P = 0.325 η^2 = 0.040	
6	N6	OND	OND	F (1, 29) = 3.368 P = 0.079 η^2 = 0.123	
7	E1	OND	OND	F (1, 29) = 1.559 P = 0.224 η^2 = 0.061	
8	E2	OND	OND	F (1, 29) = 0.035 P = 0.854 η^2 = 0.001	
9	E3	OND	OND	F (1, 29) = 0.071 P = 0.792 η^2 = 0.003	
10	E4	OND	N-OND		U = 109 P = 0.212
11	E5	OND	N-OND		U = 91 P = 0.742
12	E6	OND	N-OND		U = 96 P = 0.560
13	O1	OND	OND	F (1, 29) = 0.004 P = 0.950 η^2 = 0.000	
14	O2	OND	OND	F (1, 29) = 0.002 P = 0.968 η^2 = 0.000	
15	O3	OND	OND	F (1, 29) = 3.620 P = 0.069 η^2 = 0.131	
16	O4	N-OND	OND		U = 112 P = 0.160
17	O5*	OND	OND	F (1, 29) = 10.298 P = 0.004 η^2 = 0.300	
18	O6*	OND	N-OND		U = 128 P = 0.023
19	A1	OND	OND	F (1, 29) = 1.275 P = 0.270 η^2 = 0.050	
20	A2	OND	N-OND		U = 107.5 P = 0.231
21	A3	OND	OND	F (1, 29) = 2.494 P = 0.127 η^2 = 0.094	
22	A4	OND	OND	F (1, 29) = 0.527 P = 0.475 η^2 = 0.022	
23	A5	N-OND	OND		U = 80 P = 0.860
24	A6	OND	OND	F (1, 29) = 0.264 P = 0.612 η^2 = 0.011	
25	C1	OND	OND	F (1, 29) = 0.590 P = 0.450 η^2 = 0.024	
26	C2	OND	N-OND		U = 109.5 P = 0.193
27	C3*	OND	OND	F (1, 29) = 4.953 P = 0.036 η^2 = 0.171	
28	C4*	OND	OND	F (1, 29) = 6.403 P = 0.018 η^2 = 0.211	
29	C5	OND	OND	F (1, 29) = 3.761 P = 0.064 η^2 = 0.135	
30	C6*	OND	OND	F (1, 29) = 6.538 P = 0.017 η^2 = 0.214	

*indicates significant difference at 0.05 level.

5. Conclusion

In this study, we have confirmed the negative effect of conscientiousness on MI performance and identified several of its sub-dimensions that mediate the negative effect. In addition, we have revealed a new negative connection of openness on visually evoked MI. Further, the main sub-dimensions that can affect the MI performance are revealed. Furthermore, visually evoked MI is suggested to decrease the demand of the personality and increase the pervasive applications of MI. Research about MI indicates a difference between genders when it comes to MI-BCI performance. In future work, more quantitative measurements of personality and more factors such as gender will be studied to further study the factors that can modulate MI ability. The clinical verifications will also be made to verify the predictive ability of personality manifestation on visually evoked motor rehabilitation.

Ethics statement

The experimental protocol had been approved by the ethical review board of Shenzhen Technology University according to the Declaration of Helsinki on studies of human. All the informed consents have been collected.

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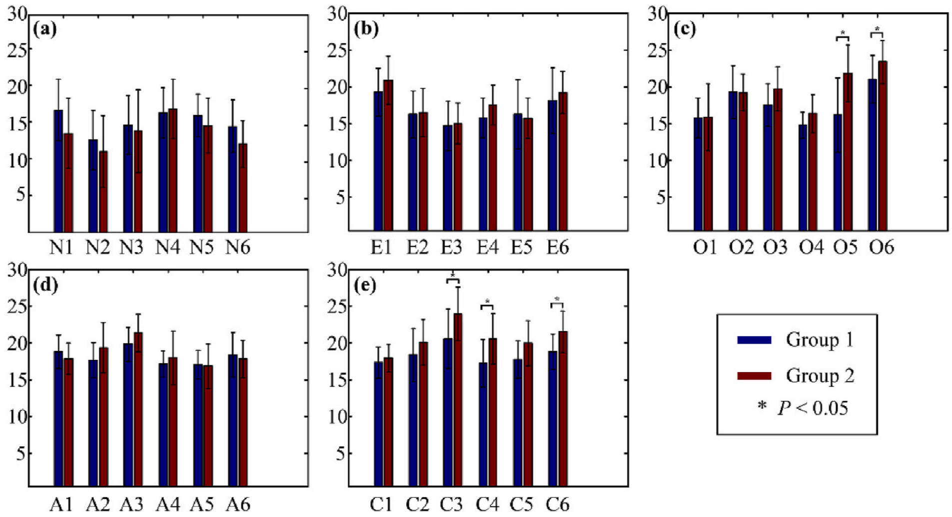

Fig. 4. The histogram of average scores of the NEO-PI-R on 30 sub-dimensions from the two groups. The blue box and red box indicate group 1 and group 2, respectively. Panel (a)–(e) represent neuroticism, extraversion, openness, agreeableness and conscientiousness.

Table 6
The Pearson correlation coefficient between classification accuracy and NEO-PI-R's five dimensions.

Paradigm	Group	Neuroticism	Extraversion	Openness	Agreeableness	Conscientiousness
Object-oriented paradigm	1	0.441	0.494	0.198	0.458	−0.025
	2	0.181	−0.285	−0.241	−0.120	0.166
No stimulus paradigm	1	−0.074	0.076	0.054	−0.363	0.066
	2	0.117	0.034	−0.453	−0.478	0.115

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Data availability statement

The datasets of this study are available from https://pan.baidu.com/s/1ocHcLyOmWw9S6kmqtL-SUQ with access number: pcaf.

CRediT authorship contribution statement

Lili Li: Writing – original draft, Methodology, Conceptualization. **Zhongliang Yu:** Software, Investigation, Funding acquisition, Conceptualization. **Hui Ma:** Writing – review & editing. **Zhibin He:** Writing – review & editing. **Zixiang Zhang:** Writing – review & editing. **Zhiqing Wu:** Visualization. **Yuze Zhang:** Writing – review & editing. **Zhizhong Wang:** Supervision. **Liyu Lin:** Supervision. **Shaolong Kuang:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e26922.

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