Social Neuroscience

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/psns20

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To cite this article: Xinuo Qiao, Kelong Lu, Jing Teng, Zhenni Gao & Ning Hao (2022) Middle occipital area differentially associates with malevolent versus benevolent creativity: An fNIRS investigation, Social Neuroscience, 17:2, 127-142, DOI: 10.1080/17470919.2022.2038261

To link to this article: https://doi.org/10.1080/17470919.2022.2038261

Published online: 10 Feb 2022.

SOCIAL NEUROSCIENCE
2022, VOL. 17, NO. 2, 127–142
https://doi.org/10.1080/17470919.2022.2038261

RESEARCH PAPER

Middle occipital area differentially associates with malevolent versus benevolent creativity: An fNIRS investigation

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ABSTRACT

This study aimed to explore the neural correlates underlying idea generation during malevolent creativity (MC) using functional near-infrared spectroscopy (fNIRS). Participants were asked to solve problems during three types of creativity tasks: malevolent creativity task (MCT), benevolent creativity task (BCT), and alternative uses task (AUT). fNIRS was used to record individual cerebral activity during the tasks. The results revealed that participants demonstrated weaker neural activation in the right middle occipital area (rMO) and lower neural coupling (NC) between the right frontopolar cortex (rFPC) and rMO during MCT than during BCT and AUT. These suggest that r-MO activity and NC between the rFPC and rMO may distinguish between malevolent and benevolent forms of creative ideation.

ARTICLE HISTORY
Received 14 May 2021
Revised 27 January 2022
Published online 13 February 2022

KEYWORDS
Creativity; malevolent creativity; fNIRS; functional connectivity

Introduction

Creativity is the ability to produce work that is novel and useful (Runco & Acar, 2012; Sternberg & Lubart, 1996) and has been relied on to attain achievements. However, despite its constructive impacts, creativity can also lead to detrimental consequences (Cropley et al., 2010; McLaren, 1993). It can be driven by antisocial purposes, such as deception, blackmail, and violence. For example, a car bomb is highly creative but can cause injury. This kind of creativity is termed as malevolent creativity (MC) that deliberately leads to harmful or immoral results (Cropley et al., 2010, 2008; Harris et al., 2013).

Previous studies on MC have mainly focused on antisocial individuals or communities, such as criminals and terrorist organizations. Eisenman (2008) identified nine creative crimes, including forging of a check without being arrested and interrogation of enemies by cutting out parts of their bodies while they were in a conscious state. Cropley et al. (2008) found that highly creative and terroristic ideas are more feasible during their conception than realization. More recently, increasing attention has been paid to MC of normal individuals (S. A. Lee & Dow, 2011; Hao et al., 2020, 2016; Harris & Reiter-Palmon, 2015). Several individual characteristics have been identified as factors that correlate with MC. Individuals with highly explicit physical aggression tend to generate more malevolent ideas during general creativity tasks (S. A. Lee & Dow, 2011). A high level of MC has been reported in individuals with higher implicit aggression (beyond one's conscious awareness) and lower premeditation (the degree of planning and forethought an individual engages in before acting; Harris & Reiter-Palmon, 2015), higher antagonism (Perchtold-Stefan et al., 2020, or lower emotion intelligence (Harris et al., 2013). In addition, two subdimensions of the Dark Triad personality (antisocial personality related to self-promotion, emotional coldness, duplicity, and aggressiveness; Paulhus & Williams, 2002), Machiavellianism (a manipulative social style that tends to lack interpersonal understanding), and psychopathy (low empathy and interpersonal coldness) are positively correlated with the harmfulness of creative ideas (Jonason et al., 2017). Moreover, individual MC can also be influenced by one's religion and social threat (Baas et al., 2019; Khorakian et al., 2020).

Although several studies have explored the factors that impact MC and have revealed several associated personality traits, none have attempted to investigate on the neural correlates that underlie idea generation in MC. Theoretically, doing so can contribute to the understanding of the mechanism of human creativity, especially that of MC, and practically, effective techniques or approaches may be developed based on the findings in relevant literature to manage and prevent antisocial MC

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behavior (especially terrorism). Thus, it is important to identify the neural correlates (i.e., related brain regions and cross-region neural coupling (NC)) that specifically contribute to MC idea generation. In the present study, functional near-infrared spectroscopy (fNIRS) was used on selected regions of interest (ROI) in the brain that were directly or indirectly associated with MC as indicated by previous studies.

The executive control network of the brain includes the lateral prefrontal and anterior inferior parietal regions and has been found to play an essential role in creative cognition (Beaty et al., 2016). For instance, the prefrontal cortex (PFC) is involved in the generation of creative ideas (Benedek et al., 2014; Wu et al., 2015). Similarly, the right temporal-parietal junction (r-TPJ), which is part of the default network, is also associated with creative cognition (Andrews-Hanna et al., 2014; Beaty et al., 2016). The r-TPJ serves as an essential brain region for memory cues and attentional control, both of which can contribute to creative performance (Fink et al., 2010, 2009b, 2012). Recent studies have shown that functional connectivity between the executive control network and the default network is related to the generation and evaluation of creative ideas (Beaty et al., 2016, 2017). The strength of functional connectivity between these two networks has also been found to be positively correlated with verbal and visual creativity (W. Zhu et al., 2017). In brief, both PFC and r-TPJ are closely associated with creativity.

As it may require individuals to violate ethical rules or reduce the inhibition of immoral ideas or behavior, we suggest that the underlying neural correlates of these behaviors may be correlated with MC based on studies that are indirectly associated with MC. The r-TPJ is recruited during both implicit and explicit moral tasks (Harenski et al., 2010). Similarly, patients who tend to engage in antisocial behavior have dysfunctional right temporal lobes (Fumagalli & Priori, 2012). A previous study has also indicated that the PFC is important for planning and supervision during moral decision-making (Fumagalli & Priori, 2012). Individuals who suffer from neural damage in the dorsolateral prefrontal cortex (DLPFC) tend to be more dishonest (L. Zhu et al., 2014). Furthermore, the right inferior frontal gyrus is associated with response inhibition (Aron et al., 2003; Chikazoe et al., 2009). Thus, we hypothesized that the PFC and r-TPJ are not only associated with creativity directly but also indirectly with MC, hence, the selection of these ROI in this study.

In this study, we aimed to explore the underlying neural correlates specific to MC idea generation. The participants were asked to perform three types of creative idea generation tasks: malevolent creativity task (MCT), benevolent creativity task (BCT), and alternative uses task (AUT). The last two tasks were used as the control tasks. In the MCT and BCT, participants were "forced" to solve different problems in MC-related or BC-related ways. These task settings were more effective in exploring neural correlates when participants used MC or BC. The neural activity of each participant was recorded using fNIRS during the task procedures. fNIRS offers the following advantages: higher tolerance of body movement (Schecklmann et al., 2010), higher ecological validity, and economy. We expected that distinguishable neural correlates specific to MC idea generation would be observed in the PFC or r-TPJ.

Method

Participants

A total of 37 participants (mean age, 21.86 ± 2.99 years; 29 females) participated in the study. Based on a priori power analysis, a sufficient sample size was 30 to obtain reliable results (Chow et al., 2017); this is comparable to those used in previous neuroscientific studies on creativity (Takeuchi et al., 2019; Tempest & Radel, 2019). All participants were right-handed and had normal or corrected-to-normal visual acuity. None had a history of mental or neurological illness. Written informed consent was obtained from all the participants before the start of the experiment. Each participant received a compensation of ¥55. The study procedure was approved by the University Committee on Human Research Protection of the East China Normal University (HR 039–2017).

Experimental procedure

Upon arrival, each participant was required to sit in front of a table that had a laptop placed on it. The experimenter prepared the fNIRS device and asked the participant to be ready. The initial session lasted 30s and served as the baseline. The participants were required to close their eyes, keep still, and relax (C.-M. Lu et al., 2010) and then they performed three types of tasks: MCT, BCT, and AUT. The study used a one-way factorial design (TASK: MCT, AUT, BCT), with TASK as the within-subject factor. The experimental procedure consisted of 15 trials involving the three tasks for three blocks (the participants were required to solve 15 MCTs, BCTs, and AUTs for each block), and their sequence was counterbalanced among the participants. Each trial began with a fixation session for 8 s, followed by a task-reading session for 10s, a thinking session for 20s, and a reporting session for 12s (Figure 1A).

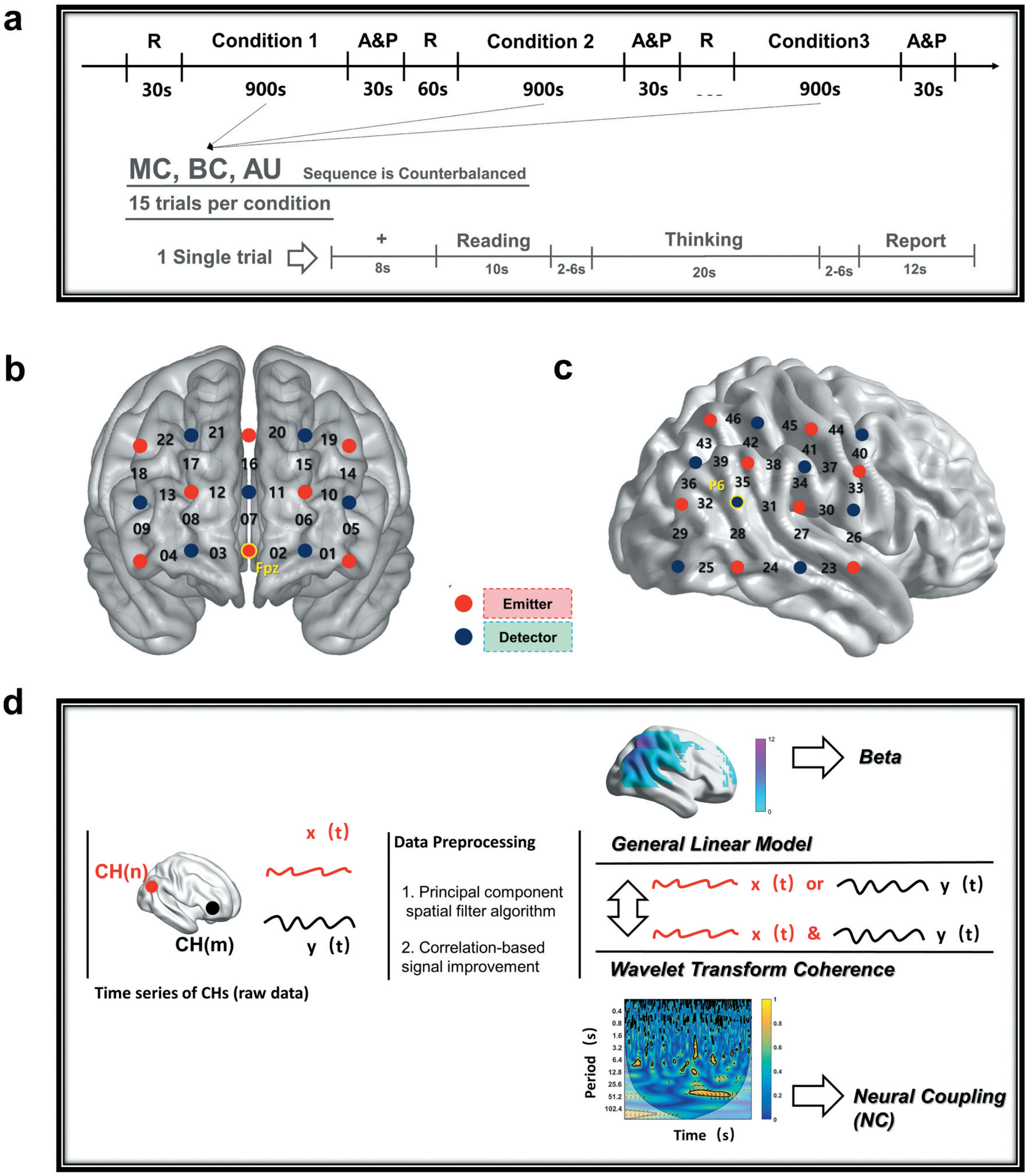

Figure 1. Experimental design in the study. (A) Experimental procedure. R: 30-second resting state session; A&P: 30-second self-rating on anxiety, pleasure, benevolence and malevolence; MC: malevolent creativity task; BC: benevolent creativity task; AU: alternative uses task. The task sequence was counterbalanced among participants. (B) Optode probe set on the prefrontal cortex. (C) Optode probe set on the right temporal and parietal regions. (D) The data pre-processing and analysis protocol.

During the reporting session, the participants were asked to verbally report their most creative idea. It should be noted that only one idea was allowed for each trial. Two jitters (blank screen, 2–6s) were introduced to separate these three sessions. At the end of each block, participants' anxiety, pleasure as well as tasks' benevolence and malevolence were reported on a 7-point Likert scale ranging from 1 (not at all) to 7 (strongly) respectively. The ratings of malevolence and benevolence were designed to validate the effectiveness of MCT and BCT (further details are provided in the "Experimental tasks" section). Moreover, there was a 1-minute resting session after each block (Figure 1A). The participants were asked to complete a series of scales immediately after the experiment (further details are provided in the "Post-experimental tests" section).

Experimental tasks

Malevolent Creativity Task (MCT): The MCT was adapted from the realistic presented problem (RPP), which requires individuals to solve an open-ended realistic problem creatively (Agnoli et al., 2016; Hao et al., 2017; Runco et al., 2016; Xue et al., 2018). To develop the MCT, 20 adapted MCTs were designed with words limited to 38–42 Chinese characters. During each MCT, the participants were asked to solve the problem by hurting others deliberately but in a creative way (e.g., Hong has a crush on someone for a long time, but a rival in love has appeared suddenly. Please generate a novel way for Hong to ruin her rival's reputation). Twenty-three participants (different from those in the actual experiment) were recruited to solve these 20 MCTs independently; they were also asked to independently rate the intelligibility, malevolence, and benevolence of these 20 tasks on a Likert scale ranging from 1 (very low) to 7 (very high). The intelligibility, malevolence, and benevolence of each MCT were then calculated by averaging the ratings received from all participants. Finally, the 15 MCTs included in this study were determined by the following criteria: (1) intelligibility was above 6, (2) malevolence was above 5, (3) benevolence was below 3, and (4) each answer was reported by less than half the sample (see original version and translated versions of MCT in Appendix Table S1).

Benevolent creativity task (BCT): The BCT was adapted from RPP. A procedure similar to that used in developing the MCT was used to develop the BCT. The 15 BCTs selected for the study were determined by the following criteria: (1) intelligibility was above 6, (2) benevolence was above 5, (3) malevolence was below 3, and (4) each answer was reported by less than half of the sample. During each BCT, the participants were required to solve the problem by helping others on their own initiative but in a creative way (for example, your friend is about to give a presentation using Microsoft PowerPoint. However, he cannot be present on time because of a traffic jam. Please generate a novel remedy to help him; see the original version and translated versions of BCT in Appendix Table S2).

Alternative use task (AUT): The AUT is a reliable test for measuring creative potential, and it has been widely used in previous studies on creativity (Fink et al., 2009a; Guilford, 1967; Hao et al., 2017; Runco & Mraz, 1992; Runco & Okuda, 1991; Wang et al., 2017). During each AUT, participants were asked to generate the most novel uses for everyday objects (e.g., Please generate a novel use for "button"). In the current study, the AUT was used to assess participants' neutral creativity (see the original version and translated versions of AUT in Appendix Tables S3).

Assessment of performance during MCT, BCT, and AUT

Participant performance in the MCT, BCT, and AUT was assessed by evaluating the originality of ideas (Runco & Okuda, 1991). Since only one idea was allowed during each trial of each task, the fluency of ideas was not assessed, and originality could not be assessed using the objective method (Lu et al., 2019). The originality score was however assessed using a subjective method that is widely used in creativity studies (Beaty et al., 2018; Lu et al., 2019b; Xue et al., 2018). Five experienced raters independently scored the originality of the generated ideas on a 5-point Likert scale (1 = not original at all, 5 = highly original). All raters had at least three years of experience in creativity research, and none of them was the coauthor of this study. The inter-rater agreement for each task was satisfactory (internal consistency coefficient [ICC]; ICC $_{[MCT]}$ = .78, ICC $_{[BCT]}$ = .83, ICC $_{[AUT]}$ = .79). The originality score for each idea was calculated by averaging the scores received from all five raters. The final originality scores for the participants were calculated by averaging the originality scores of all their ideas. The harmfulness of the ideas generated during the MCT was independently assessed on a 5-point Likert scale (1 = not harmful at all, 5 = highly harmful) by five experienced raters. The inter-rater consistency for harmfulness was satisfactory (ICC = .83). The method for obtaining the final harmfulness score for each participant was the same as that used for the originality score.

Post-experimental tests

The participants' creativity potential was evaluated based on their scores on the Runco Ideational Behavior Scale (RIBS; e.g., I have some ideas about making my job easier; Runco et al., 2016). This scale contains 19 items rated on a 5-point Likert scale ranging from 0 (never) to 4 (just about every day). The internal consistency reliability of the RIBS was satisfactory (Cronbach's α = .82). The participants' malevolent creativity potential was evaluated based on their scores on the Malevolent Creativity Behavior Scale (MCBS). The MCBS contains 13 items rated on a 5-point Likert scale ranging from 1 (never) to 5 (always; e.g., I can think of many ideas to prank others; Hao et al., 2016). The internal consistency reliability of the MCBS was satisfactory (Cronbach's α = .91).

The Dark Triad personality traits (narcissism, psychopathy, and Machiavellianism) of the participants were assessed using the Chinese version of the Dirty Dozen (DD12; e.g., I am used to get my own way by cheating others; Geng et al., 2015). The DD12 contains 12 items rated on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). The internal consistency reliability of the DD12 was satisfactory (Cronbach's α = .81). The moral personalities of the participants were evaluated using the Honesty-Humility Inventory (e.g., having a lot of money is not really important to me; Ho-Hu; K. Lee & Ashton, 2004). The Ho-Hu contains 20 items rated on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The internal consistency reliability of the Ho-Hu was satisfactory (Cronbach's α = .72).

fNIRS data acquisition

The concentrations of oxyhemoglobin (HbO) and deoxyhemoglobin (HbR) for each participant were continuously recorded using an fNIRS system (ETG-7100, Hitachi Medical Corporation, Japan) throughout the experiment. The absorption of near-infrared light (wavelengths 695 and 830 nm) was assessed at a sampling rate of 10 Hz. One 3 × 5 probe set and one 4 × 4 probe set were used accordingly in this study. Previous studies have shown that creativity is related to the PFC and r-TPJ (Beaty et al., 2016; Heinonen et al., 2016), and these were selected as ROIs. The probe sets were placed on the PFC (3 × 5 probe set) and the right temporal and parietal regions (covering the r-TPJ) (4 × 4 probe set) of each participant. Using the 10–20 system, the lowest row of the 3 × 5 probe set (eight emitters and seven detectors, 3 cm optode separation, forming 22 measurement channels) was aligned with the Fp1–Fp2 line, and the optode "A" was positioned on the frontal pole midline point (Fpz; Sai et al., 2014). Meanwhile, the middle probe column of the 3 × 5 probe set was aligned along the sagittal reference curve (Figure 1B). The 4 × 4 probe set (eight emitters and eight detectors, 3 cm optode separation, forming 24 measurement channels) was aligned with the sagittal reference curve, and the optode "B" was positioned on P6 (Figure 1C). The virtual registration method was used to ascertain the correspondence between the channels and the measurement points in the cortex (Singh et al., 2005; Tsuzuki et al., 2007).

fNIRS data pre-processing

During data pre-processing, the global components in the raw fNIRS data were removed by a principal component spatial filter algorithm (Zhang et al., 2016), and motion artifacts were removed using a correlation-based signal improvement method (Cui et al., 2012; Pan et al., 2018; Figure 1(D)). With the correlation-based signal improvement method, the HbO and HbR signals are assumed to be negatively correlated, and thereby the corrected HbR is solely the corrected HbO multiplied by a negative coefficient (Cui et al., 2010). We mainly focused the subsequent analyses on HbO signals here. Channels with poor signals were determined by visually checking the NIRS time-course plot. If one channel had a considerably higher variance than other channels of the same participant, it was accordingly identified as a poor channel (for example, the variances of poor channels were 10–30, while the variances of normal channels were 0.5 ~ 0.8). If a third of the sample had poor signals at a particular channel, the corresponding data were excluded from subsequent analyses. Hence, the data of CH5, CH9, CH18, CH21, CH33, CH37, and CH40 were accordingly excluded.

Data analysis of the neural activation

The NIRS Statistical Parametric Mapping (NIRS_SPM) package was used to estimate individual neural activation (Jang et al., 2009; Ye et al., 2009). The hrf low-pass filtering and wavelet minimum description length detrending algorithm were selected as required by NIRS_SPM. Neural activation during the entire thinking stage (0–20 s) was estimated using the general linear model (Figure 1D). A reference wave was set for each channel during all experimental conditions (MCT, BCT, AUT, and baseline) to represent the theoretical variations in HbO signals induced by the experimental stimulus. A regression involving the theoretical HbO signal variations and real HbO signal variations during the task period was performed for each channel. Several beta (β) values were obtained as regression coefficients for all channels under different conditions. The beta value indicates the variation in neural activation. Subsequently, the beta increment was calculated by subtracting the baseline beta value from the thinking session beta value. The beta increments were transformed into Z-scores channel-by-channel across participants before further analyses.

A total of 39 one-way ANOVAs with repeated measures, using the TASK as the within-subject factor, were performed on the beta increments from 39 normal CHs. The resulting *p-values* were corrected using the false discovery rate correction method (FDR; corrected alpha level = 0.05). A follow-up post-hoc test was performed with Bonferroni correction when necessary.

Pearson correlation was used to quantify the relationship between the beta increments from all the CHs and behavioral performance (including task performance and scores on scales from post-experimental tests). The resulting *p* values were corrected using the FDR method (the FDR correction was performed within each behavioral index; corrected alpha level = 0.05).

Data analysis of neural coupling (NC)

Neural coupling was used to measure the functional connectivity between different cerebral regions. Furthermore, the wavelet transform coherence (WTC) was used to calculate the NC between the HbO time series obtained from different cerebral regions (Grinsted et al., 2004; Figure 1(D)). The Morlet wavelet (wavenumber = 6), time smoothing (Gaussian function for the Morlet wavelet), and scale smoothing (boxcar with width of 0.6) were applied (Grinsted, 2014) during the WTC calculation. For each participant, we calculated the NC between the different CHs in each trial under different task conditions. The NC of each task condition was calculated by averaging the NC values obtained during the 20-second thinking sessions from all 15 trials for that condition. The NC values were converted to Fisher's z-statistics before they were used for further analyses (Chang & Glover, 2010; Cui et al., 2012).

According to previous studies, the frequency band of interest for the WTC analysis is usually determined based on the inverse of the time interval between two continuous parts in single trials (Hu et al., 2017; Xue et al., 2018; Yang et al., 2020). In this study, the time length of the thinking stage and a single trial were 20 and 58s, respectively. The frequency band of interest was determined based on these two time lengths (i.e., the frequency band ranging from 0.0168 Hz to 0.0505 Hz (corresponding to the time length of 19–59 seconds), which covered the time range of "20 ~ 58 seconds." This frequency band also eliminated Mayer waves (~0.1 Hz), high-frequency physiological noise (i.e., cardiac activity, 0.8–2.5 Hz), and very low-frequency fluctuations (Barrett et al., 2016; Tong et al., 2011). Initially, there were 2,116 CH combinations (46 × 46 CHs), with 1,081 redundant CH combinations (equal CH combinations or CH combinations of a single CH, i.e., CH1-CH1). Since the CH combinations with poor channels were excluded in this study (CH combinations containing CH5, CH9, CH18, CH21, CH33, CH37, and CH40; see details in fNIRS data pre-processing), only 741 CH combinations were finally entered into the subsequent analyses. For each CH combination, the NC values in the frequency band of interest were averaged and subsequently used for statistical analyses. One-way ANOVA with repeated measures, using TASK as the within-subject factor, was used to analyze the NC value of each channel (CH) combination. The results were FDR-corrected across all CH combinations (a total of 741 combinations; corrected alpha level = 0.05). A follow-up post-hoc test was performed using Bonferroni correction.

A similar Pearson correlation was used to quantify the relationship between the NC values from all CH combinations and behavioral performances. The resulting *p-values* were corrected using the FDR method (the FDR correction was performed within each behavioral index; corrected alpha level = 0.05).

Results

Behavioral indices in different task conditions

One-way ANOVAs with repeated measures, using TASK as the within-subject factor, were used to evaluate anxiety, pleasure, benevolence, and malevolence (see, Table 1).

The results showed that the tasks significantly influenced anxiety (F (2, 72) = 4.33, p = .017, η_p^2 = .11). The post-hoc test (Bonferroni corrected) revealed that anxiety was significantly higher during the MCT than during the BCT (p = .010) and AUT (p = .009). The results also showed a significant influence of TASK on pleasure (F (2,

Table 1. The results of one-way repeated measures ANOVAs with TASK as the within-subject factor on the anxiety, pleasure, benevolence and malevolence. The post-hoc tests were Bonferroni corrected.

	MCT($M \pm SD$)	BCT($M \pm SD$)	AUT($M \pm SD$)	F(2, 72)	p	η_p^2	Post-hoc
Anxiety	4.43 ± 1.42	3.70 ± 1.41	3.73 ± 1.56	4.33	.017	.11	MCT>BCT* MCT>AUT**
Pleasure	2.38 ± 1.01	3.59 ± 1.48	3.22 ± 1.27	12.69	.000	.26	BCT>MCT*** AUT>MCT**
Benevolence	1.89 ± .91	5.54 ± 1.17	4.38 ± 1.59	95.52	.000	.73	BCT>MCT*** BCT>AUT*** AUT>MCT***
Malevolence	5.92 ± .89	1.86 ± .89	2.38 ± 1.30	198.35	.000	.85	MCT>BCT*** MCT>AUT*** AUT>BCT*

Note: *p < 0.05; **p < 0.01; ***p < 0.001;

72) = 12.69, $p < .001$, $\eta_p^2 = .26$). The post-hoc test revealed that pleasure was significantly lower during the MCT than during the BCT ($p < .001$) and AUT ($p = .003$).

Furthermore, the TASK significantly influenced benevolence (F (2, 72) = 95.52, $p < .001$, $\eta_p^2 = .73$). The post-hoc test (Bonferroni corrected) revealed that benevolence was significantly lower during the MCT than during the BCT ($p < .001$) and AUT ($p < .001$). Benevolence during AUT was significantly lower than that during BCT ($p < .001$). TASK also significantly influenced malevolence (F (2, 72) = 198.35, $p < .001$, $\eta_p^2 = .85$). The post-hoc test (Bonferroni corrected) revealed that malevolence was significantly higher during the MCT than during the BCT ($p < .001$) and AUT ($p < .001$). Malevolence during AUT was significantly higher than that during BCT ($p = .033$). These results partly confirm the effectiveness of the MCT and BCT.

Differences between the beta increments for the different task conditions

One-way ANOVAs with repeated measures, using TASK as the within-subject factor, were used to analyze the beta increments of the effective CHs (i.e., CHs that survived the signal examination procedure; Figure 2). The individual data identified as poor signals were excluded for each CH. After FDR correction ($p < .05$, a total of 39 channels), the results revealed that TASK significantly influenced the beta increment at CH29 (F (2,62) = 7.50, $p = .046$, $\eta_p^2 = .20$; Figure 2C). Post-hoc tests (Bonferroni corrected) showed that the beta increment at CH29 was significantly lower during the MCT ($M = -.12$, $SD = 1.02$) than during the BCT ($M = .05$, $SD = 1.02$, $p = .016$) and AUT ($M = .06$, $SD = .98$, $p = .011$; Figure 2C).

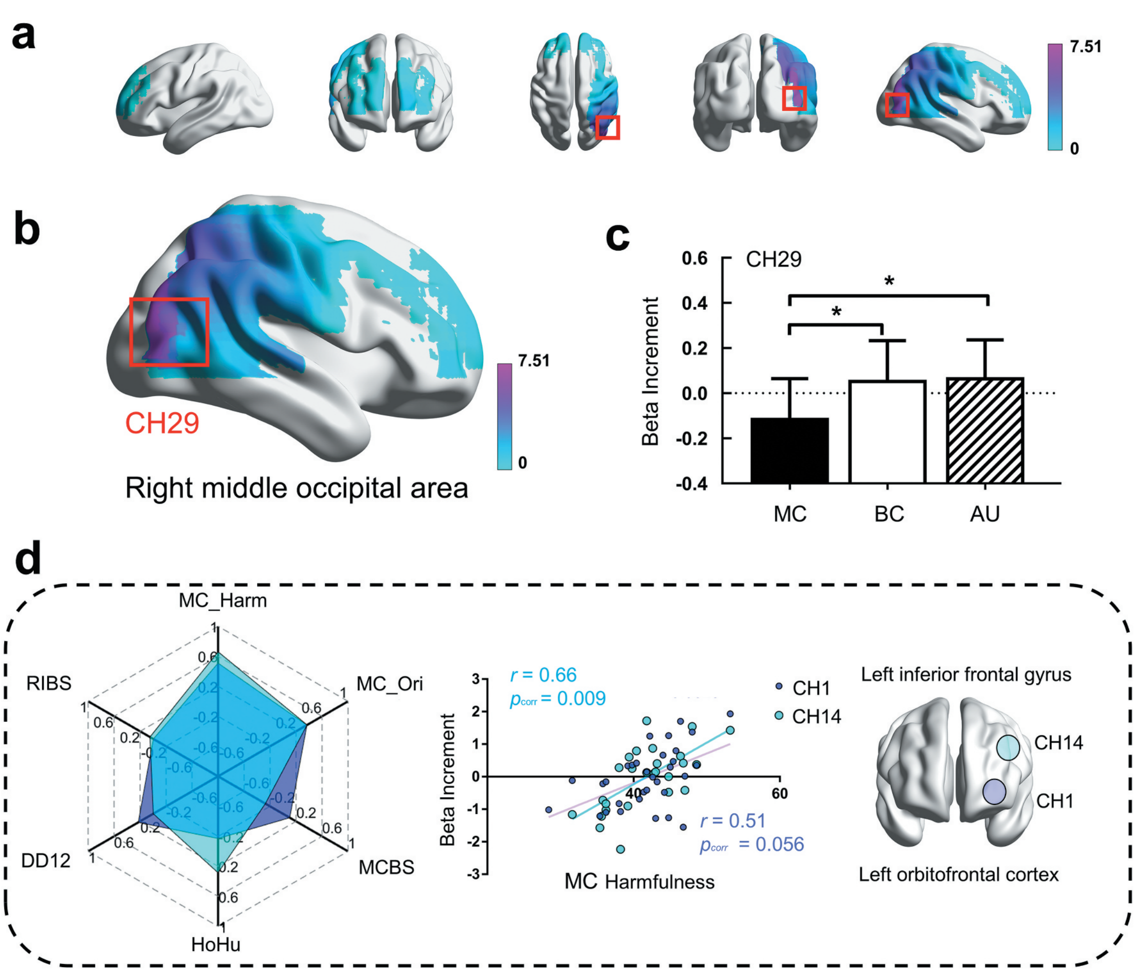

Figure 2. Analyses on beta increment (FDR-corrected). (A) The full views of main effect of TASK on the beta increment of all CHs. The red rectangle indicate that the CH has a significant main effect (CH29). (B) The location of CH29 on the cerebral cortex. (C) The amplitude of beta increment of CH29. The color bar denotes the F values. *$p < 0.05$. (D) The radar plot and scatter plot display the correlations between beta increment of CH1, CH14 and behavioral indices. MC_Harm denotes MC harmfulness, MC_Ori denotes MC originality.

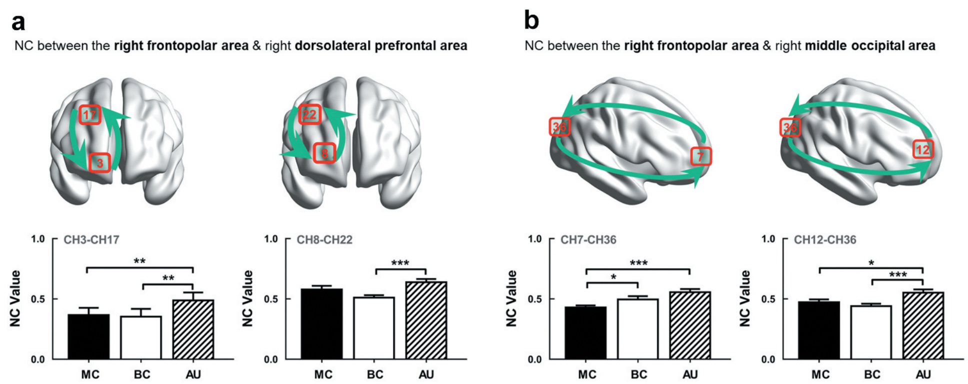

Figure 3. Analyses on NC value (FDR-corrected). (A) The amplitude of NC values of CH3-CH17, CH8-CH22 and their locations on the cerebral cortex. (B) The amplitude of NC values of CH7-CH36, CH12-CH36 and their locations on the cerebral cortex. *p < 0.05, **p < 0.01, ***p < 0.001.

Differences in neural coupling during different task conditions

Several one-way ANOVAs with repeated measures, using TASK as the within-subject factor, were used to analyze the NC values of the effective CH combinations (i.e. CH combinations with effective CHs; Figure 3). The individual data identified as poor signals were excluded for each CH combination. After FDR correction ($p < .05$), the results revealed that TASK significantly influenced the NC values for the following CH combinations:CH3-CH17, CH8-CH22, CH7-CH36, CH12-CH36, and CH42-CH43. Since CH42 and CH43 were in the same region, this result was not included in the further analyses.

Specifically, the post-hoc tests (Bonferroni corrected) showed that the NC value of CH3-CH17 was significantly higher during the AUT than during the MCT ($p = .001$) and BCT ($p = .002$; Figure 3A). The NC value of CH8-CH22 was significantly higher during the AUT than during the BCT ($p < .001$; Figure 3A). The NC value of CH7-CH36 was significantly lower during MCT than during BCT ($p = .019$) and AUT ($p < .001$; Figure 3B). The NC value of CH12-CH36 was significantly higher during the AUT than during the MCT ($p = .017$) and BCT ($p < .001$; Figure 3B). Please see the detailed statistics in Table 2.

Considering that anxiety and pleasure were significantly different across the three tasks, the linear mix model was used to control the potential effect of anxiety and pleasure on the neural results (see details in Appendix Table S4 and Table S5). The ANOVA results were still significant after controlling for the effects of anxiety and pleasure. This suggests that these findings were not influenced by anxiety or pleasure.

Correlations between cerebral activity and behavioral performance

Pearson correlation was used to quantify the relationship between the beta increments during the MCT from all remaining CHs and behavioral performance. The individual data identified as poor signals were excluded for each CH. Results showed that the MC harmfulness was significantly and positively correlated with the beta increment at CH14 ($r = .66$, $p_{corr} = .009$; Figure 2D) and the MC harmfulness was marginally and positively correlated with the beta increment at CH1 ($r = .51$, $p_{corr} = .056$; Figure 2D). None of the correlations between NC values and behavioral performance were significant after FDR correction.

To examine whether the observed neural responses were more related to the harmfulness required or induced by the task or the harmfulness produced by participants, Pearson correlation was used to quantify the relationship between the average beta increment at CH1 and CH14 and the harmfulness of each MCT. The

Table 2. The results of one-way repeated measures ANOVAs with TASK as the within-subject factor on the NC values. Only CH combinations that survived the FDR correction were listed below. The post-hoc tests were Bonferroni corrected.

CH combination	MCT($M \pm SD$)	BCT($M \pm SD$)	AUT($M \pm SD$)	F	p(FDR)	η_p^2	Post-hoc
CH3-CH17	.55 ± .13	.56 ± .14	.70 ± .16	12.54 (2, 48)	.015	.34	AUT>BCT** AUT>MCT**
CH8-CH22	.58 ± .15	.51 ± .10	.64 ± .13	10.04 (2, 48)	.034	.30	BCT<AUT***
CH7-CH36	.43 ± .09	.50 ± .14	.56 ± .14	13.18 (2, 56)	.015	.32	MCT<BCT* MCT<AUT***
CH12-CH36	.47 ± .13	.44 ± .11	.55 ± .15	13.53 (2, 58)	.019	.28	AUT>BCT*** AUT>MCT*

Note: *p < 0.05; **p < 0.01; ***p < 0.001;

results showed that no significant correlation was observed between these two variables (CH1: $r = -.09$, $p = .756$; CH14: $r = .15$, $p = .591$).

Discussion

In this study, we used the fNIRS technique to show the neural correlates underlying idea generation during MC by comparing the neural activities during the MCT, BCT, and AUT. To the best of our knowledge, this is the first study to explore the neural correlates underlying idea generation and processing in MC. Participants were required to complete the MCT, BCT, and AUT, during which individual neural activities were recorded using fNIRS. The results showed that CH29 (the right middle occipital area, rMO) was less activated during the MCT than during the BCT and AUT. The NC value of CH3-CH17 (right frontopolar cortex and right dorsolateral prefrontal cortex, rFPC-rDLPFC) was lower during the MCT and BCT than during the AUT; the NC value of CH8-CH22 (rFPC-rDLPFC) was lower during the BCT than during the AUT; the NC value of CH7-CH36 (rFPC-rMO) was lower during the MCT than during the BCT and AUT; and the NC value of CH12-CH36 (rFPC-rMO) was lower during the MCT and BCT than during the AUT.

Specifically, we found weaker neural activation at CH29 (roughly located at the r-MO) during the MCT than during the BCT and AUT. Several previous studies have confirmed that the occipital area, which is involved in repetitive violence, tends to suffer from dysplasia and dysfunction. For instance, the gray matter volume of the middle occipital gyrus was lower in psychopaths than in normal individuals (De Oliveira-souza et al., 2008). Patients with conduct disorders have weaker functional connectivity within the bilateral middle occipital gyrus (Lu et al., 2020, 2017). The gray matter volume of the bilateral occipital area was lower in psychopathic violent criminals than in normal individuals (Bertsch et al., 2013; Bogerts et al., 2018). Furthermore, activation of the occipital area was found to be related to moral judgment (Cheng et al., 2021). Accordingly, deactivation of the occipital area may be accompanied by the dysfunction of normal moral judgment. In this case, the lower activation at r-MO during the MCT might reflect that participants' criterion of moral judgment declined when compared to the BCT and AUT. Such a moral standard declination allowed the generation of immoral or unethical ideas and eventually helped support the generation of malevolent creative ideas in the participant.

Neural coupling analysis showed that the NC value of CH7-CH36 (i.e., rFPC-rMO) was significantly lower during the MCT than during the BCT and AUT. The NC value of CH12-CH36 (i.e., rFPC-rMO) was significantly lower during the MCT and BCT than during the AUT. We found that r-MO was less activated in the MCT (see details in Results: *Differences between the beta increments for the different task conditions*), which might be associated with immoral behaviors (Bertsch et al., 2013; Bogerts et al., 2018; Lu et al., 2020, 2017; De Oliveira-souza et al., 2008). The frontopolar cortex is involved in generating creative solutions (Bendetowicz et al., 2017; Green et al., 2012; De Souza et al., 2014). On these grounds, lower NC values for the rFPC and rMO during MCT might indicate that participants were trying to generate both novel and immoral ideas. That is, MC more heavily emphasized the coordination between "be creative" and "be immoral" than BC or neutral creativity.

We also observed that the NC value of CH3-CH17 (i.e., rFPC-rDLPFC) was significantly lower during the MCT and BCT than during the AUT. The NC value of CH8-CH22 (i.e., rFPC-rDLPFC) was significantly lower during the BCT than during the AUT. The frontopolar cortex is related to creative ideas generation (Bendetowicz et al., 2017; Green et al., 2012; De Souza et al., 2014). It has been found that rDLPFC involves in self-other overlap, which might reduce the distinction between self and others (Feng et al., 2020). Considering that MCT and BCT contained social interaction (hurting or helping others in a novel way), lower NC value for rFPC and rDLPFC might indicate that participants were keeping the distinction between self and others in the process of solving social-creativity problems. This result might indicate that to "be a villain" and to "be a savior" were not completely opposed, but they had certain commonalities in the participants.

The correlation analysis demonstrated positive correlations between MC harmfulness and neural activation at CH1 (the left orbitofrontal cortex) and CH14 (the left inferior frontal gyrus) during the MCT. The left orbitofrontal cortex has been reported to be associated with trait hostility (Besteher et al., 2017; Quan et al., 2019). Furthermore, the left inferior frontal gyrus is related to the processing of social information (Kana et al., 2017; Wood et al., 2003; Zahn et al., 2007). Disrupting the activation of the left inferior frontal gyrus hinders individual performance during a social perception task (Keuken et al., 2011). Accordingly, these findings suggest that the left inferior frontal gyrus is associated with relative social information processing during MCT (such as how to harm the target person). Furthermore, the left orbitofrontal cortex may contribute to individual hostility, which allows individuals to behave aggressively and promote harmful ideation.

We suggest that these findings have both theoretical and practical implications. Theoretically, they contribute to the understanding of the brain regions that distinguish between malevolent and benevolent creativity or neutral creativity, such as rMO, rFPC, and rDLPFC. Practically, the involvement of rMO, which is related to moral judgment, in MC idea generation might suggest that more attention should be paid to moral education.

However, this study has several limitations that should be noted accordingly. Primary, we suggest there are three distinctive and complementary approaches to unveil the neural substrate of MC: (1) Comparing individual brain activities during malevolent creativity task and other creativity tasks; (2) Comparing individual brain activities during generating malevolent creative (more creative) ideas and non-creative (less creative) ideas; (3) Comparing individual brain activities during generating creative malevolent ideas between the high-MC individuals (e.g., incarcerated criminals) and low-MC individuals (e.g., ordinary citizen). Although the current study only relied on the first approach, the neural mechanism underlying MC should be further unveiled by studies using the other approaches. Owing to the limited spatial resolution of the device, only the outer cortex in the bilateral PFC and the right temporal and parietal regions were explored in this study. Subcortical areas may also be involved in idea generation in MC. For instance, the hippocampus is associated with monitoring and controlling aggression (Fumagalli & Priori, 2012; Van Goozen & Fairchild, 2006), and the amygdala is related to moral transgression (Blair, 2007). These subcortical areas may contribute to idea generation in MC. Therefore, devices with higher spatial resolution, such as fMRI and MEG, should be employed to meticulously explore the neural correlates that underlie idea generation in MC, especially those that are deep in the brain. Second, although the AUT is widely used to assess individuals' neutral creativity potential, it may require a different set of thinking processes compared with the MCT and BCT. Therefore, a more appropriate control task (i.e., a task with a set of thinking processes similar to the other tasks) should be used to assess an individual's neutral creativity potential in future studies. The MCT and BCT were not identical in the task situation, which might have activated different brain regions in these participants. A new set of MCT and BCT with the same task situation should hence be developed in future studies. Besides, the 1st person approach was applied to BCT, whereas the 3rd person approach was to MCT. Whether the findings were contaminated by the person approaches (e.g., 1st or 3rd) applied to task scenarios should be examined in future studies. Moreover, as Perchtold-Stefan et al. (2020) suggested, scenarios with a high level of provocation feeling can stimulate individual malevolent creativity most. The MCT scenarios in future studies should be constructed with a high level of provocation feeling. Third, the sample in this study was gender unbalanced; therefore, the potential effect of gender differences could not be excluded accordingly. Future studies should examine the potential gender differences in neural correlates that underlie idea generation in MC. Fourth, although 15 MCT and BCT were used in this study, the potential contaminative effect of the different sets of action demands from these task items on the current findings requires further investigation. Otherwise, a novel design was adopted in this study. For instance, one could systematically ask participants to address an identical set of problems, however under conditions where harmful intentions were necessary or preferable from the participant's perspective. It should be noted that the current findings only elucidate relative neural correlates that underlie idea generation during MC, and they are specific to ideas created in the laboratory experiment. However, other brain regions (especially those below the outer cortex) may be involved in MC-related problem solving in real-life situations involving complex social events. Therefore, caution should be exercised when generalizing the findings of this study.

Acknowledgments

This work was sponsored by the Humanity and Social Science foundation of Ministry of Education of China (17YJA190007) and the National Natural Science Foundation of China (31971002) to NH.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the National Natural Science Foundation of China [31971002]; Humanity and Social Science foundation of Ministry of Education of China [17YJA190007].

References

Agnoli, S., Corazza, G. E., & Runco, M. A. (2016). Estimating creativity with a multiple-measurement approach within scientific and artistic domain. *Creativity Research Journal*, *28*(2), 171–178. https://doi.org/10.1080/10400419.2016.1162475

Andrews-Hanna, J. R., Smallwood, J., & Spreng, R. N. (2014). The default network and self-generated thought: Component processes, dynamic control, and clinical relevance. *Annals of the New York Academy of Sciences*, *1316* (1), 29. https://doi.org/10.1111/nyas.12360

Aron, A. R., Fletcher, P. C., Bullmore, E. T., Sahakian, B. J., & Robbins, T. W. (2003). Stop-signal inhibition disrupted by damage to right inferior frontal gyrus in humans. *Nature Neuroscience*, *6*(2), 115–116. https://doi.org/10.1038/nn1003

Baas, M., Roskes, M., Koch, S., Cheng, Y., & De Dreu, C. K. W. (2019). Why social threat motivates malevolent creativity. *Personality & Social Psychology Bulletin*, *45*(11), 1590–1602. https://doi.org/10.1177/0146167219838551

Barrett, K. E., Barman, S. M., Boitano, S., & Brooks, H. (2016). *Ganong's review of medical physiology* (25th ed.). McGraw-Hill Education LLC.

Beaty, R. E., Benedek, M., Silvia, P. J., & Schacter, D. L. (2016). Creative cognition and brain network dynamics. *Trends in Cognitive Sciences*, *20*(2), 87–95. https://doi.org/10.1016/j.tics.2015.10.004

Beaty, R. E., Christensen, A. P., Benedek, M., Silvia, P. J., & Schacter, D. L. (2017). Creative constraints: Brain activity and network dynamics underlying semantic interference during idea production. *NeuroImage*, *148*, 189–196. https://doi.org/10.1016/j.neuroimage.2017.01.012

Beaty, R. E., Kenett, Y. N., Christensen, A. P., Rosenberg, M. D., Benedek, M., Chen, Q., Fink, A., Qiu, J., Kwapil, T. R., Kane, M. J., & Silvia, P. J. (2018). Robust prediction of individual creative ability from brain functional connectivity. *Proceedings of the National Academy of Sciences*, *115*(5), 1087–1092. https://doi.org/10.1073/pnas.1713532115

Bendetowicz, D., Urbanski, M., Aichelburg, C., Levy, R., & Volle, E. (2017). Brain morphometry predicts individual creative potential and the ability to combine remote ideas. *Cortex*, *86*, 216–229. https://doi.org/10.1016/j.cortex.2016.10.021

Benedek, M., Jauk, E., Fink, A., Koschutnig, K., Reishofer, G., Ebner, F., & Neubauer, A. C. (2014). To create or to recall? Neural mechanisms underlying the generation of creative new ideas. *NeuroImage*, *88*, 125–133. https://doi.org/10.1016/j.neuroimage.2013.11.021

Bertsch, K., Grothe, M., Prehn, K., Vohs, K., Berger, C., Hauenstein, K., Keiper, P., Domes, G., Teipel, S., & Herpertz, S. C. (2013). Brain volumes differ between diagnostic groups of violent criminal offenders. *European Archives of Psychiatry and C Linical N Euroscience*, *263*(7), 593–606. https://doi.org/10.1007/s00406-013-0391-6

Besteher, B., Squarcina, L., Spalthoff, R., Bellani, M., Gaser, C., Brambilla, P., & Nenadić, I. (2017). Brain structural correlates of irritability: Findings in a large healthy cohort. *Human Brain Mapping*, *38*(12), 6230–6238. https://doi.org/10.1002/hbm.23824

Blair, R. J. R. (2007). The amygdala and ventromedial prefrontal cortex in morality and psychopathy. *Trends in Cognitive Sciences*, *11*(9), 387–392. https://doi.org/10.1016/j.tics.2007.07.003

Bogerts, B., Schöne, M., & Breitschuh, S. (2018). Brain alterations potentially associated with aggression and terrorism. *CNS Spectrums*, *23*(2), 129–140. https://doi.org/10.1017/S1092852917000463

Chang, C., & Glover, G. H. (2010). Time–frequency dynamics of resting-state brain connectivity measured with fMRI. *NeuroImage*, *50*(1), 81–98. https://doi.org/10.1016/j.neuroimage.2009.12.011

Cheng, Q., Wen, X., Ye, G., Liu, Y., Kong, Y., & Mo, L. (2021). Neural underpinnings of morality judgment and moral aesthetic judgment. *Scientific Reports*, *11*(1), 18232. https://doi.org/10.1038/s41598-021-97782-7

Chikazoe, J., Jimura, K., Asari, T., Yamashita, K.-I., Morimoto, H., Hirose, S., Miyashita, Y., & Konishi, S. (2009). Functional dissociation in right inferior frontal cortex during performance of go/no-go task. *Cerebral Cortex*, *19*(1), 146–152. https://doi.org/10.1093/cercor/bhn065

Chow, S. C., Shao, J., Wang, H., & Lokhnygina, Y. (2017). *Sample size calculations in clinical research* (3th ed.). Chapman and Hall/CRC.

Cropley, D. H., Cropley, A. J., Kaufman, J. C., & Runco, M. A. (2010). *The dark side of creativity*. Cambridge University Press.

Cropley, D. H., Kaufman, J. C., & Cropley, A. J. (2008). Malevolent creativity: A functional model of creativity in terrorism and crime. *Creativity Research Journal*, *20*(2), 105–115. https://doi.org/10.1080/10400410802059424

Cui, X., Bray, S., & Reiss, A. L. (2010). Functional near infrared spectroscopy (NIRS) signal improvement based on negative correlation between oxygenated and deoxygenated hemoglobin dynamics. *NeuroImage*, *49*(4), 3039–3046. https://doi.org/10.1016/j.neuroimage.2009.11.050

Cui, X., Bryant, D. M., & Reiss, A. L. (2012). NIRS-based hyperscanning reveals increased interpersonal coherence in superior frontal cortex during cooperation. *NeuroImage*, *59*(3), 2430–2437. https://doi.org/10.1016/j.neuroimage.2011.09.003

de Oliveira-souza, R., Hare, R. D., Bramati, I. E., Garrido, G. J., Azevedo Ignácio, F., Tovar-Moll, F., & Moll, J. (2008). Psychopathy as a disorder of the moral brain: Fronto-temporo-limbic grey matter reductions demonstrated by voxel-based morphometry. *NeuroImage*, *40*(3), 1202–1213. https://doi.org/10.1016/j.neuroimage.2007.12.054

de Souza, L. C., Guimarães, H. C., Teixeira, A. L., Caramelli, P., Levy, R., Dubois, B., & Volle, E. (2014). Frontal lobe neurology and the creative mind. *Frontiers in Psychology*, *5*, 761. https://doi.org/10.3389/fpsyg.2014.00761

Eisenman, R. (2008). Malevolent creativity in criminals. *Creativity Research Journal*, *20*(2), 116–119. https://doi.org/10.1080/10400410802059465

Feng, X., Sun, B., Chen, C., Li, W., Wang, Y., Zhang, W., Xiao, W., & Shao, Y. (2020). Self–other overlap and interpersonal neural synchronization serially mediate the effect of behavioral synchronization on prosociality. *Social Cognitive and Affective Neuroscience*, *15*(2), 203–214. https://doi.org/10.1093/scan/nsaa017

Fink, A., Grabner, R. H., Benedek, M., Reishofer, G., Hauswirth, V., Fally, M., Neuper, C., Ebner, F., & Neubauer, A. C. (2009a). The creative brain: Investigation of brain activity during creative problem solving by means of EEG and fMRI. *Human Brain Mapping*, *30*(3), 734–748. https://doi.org/10.1002/hbm.20538

Fink, A., Grabner, R. H., Gebauer, D., Reishofer, G., Koschutnig, K., & Ebner, F. (2010). Enhancing creativity by means of cognitive stimulation: Evidence from an fMRI study. *NeuroImage*, *52*(4), 1687–1695. https://doi.org/10.1016/j.neuroimage.2010.05.072

Fink, A., Graif, B., & Neubauer, A. C. (2009b). Brain correlates underlying creative thinking: EEG alpha activity in professional vs. novice dancers. *NeuroImage*, *46*(3), 854–862. https://doi.org/10.1016/j.neuroimage.2009.02.036

Fink, A., Koschutnig, K., Benedek, M., Reishofer, G., Ischebeck, A., Weiss, E. M., & Ebner, F. (2012). Stimulating creativity via the exposure to other people's ideas. *Human Brain Mapping*, *33*(11), 2603–2610. https://doi.org/10.1002/hbm.21387

Fumagalli, M., & Priori, A. (2012). Functional and clinical neuroanatomy of morality. *Brain: A Journal of Neurology*, *135*(7), 2006–2021. https://doi.org/10.1093/brain/awr334

Geng, Y., Sun, Q., Huang, Q., Zhu, Y., & Han, X. (2015). Dirty dozen and short dark triad: A Chinese validation of two brief measures of the dark triad. *Chinese Journal of Clinical Psychology*, *23*(2), 246–250. https://doi.org/10.16128/j.cnki.1005-3611.2015.02.013

Green, A. E., Kraemer, D. J. M., Fugelsang, J. A., Gray, J. R., & Dunbar, K. N. (2012). Neural correlates of creativity in analogical reasoning. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *38*(2), 264–272. https://doi.org/10.1037/a0025764

Grinsted, A. (2014). *Cross wavelet and wavelet coherence. GitHub*. Retrieved October 14, 2021, from https://github.com/grinsted/wavelet-coherence

Grinsted, A., Moore, J. C., & Jevrejeva, S. (2004). Application of the cross wavelet transform and wavelet coherence to geophysical time series. *Nonlinear Processes in Geophysics*, *11*(5/6), 561–566. https://doi.org/10.5194/npg-11-561-2004

Guilford, J. P. (1967). *The nature of human intelligence*. McGraw-Hill.

Hao, N., Qiao, X., Cheng, R., Lu, K., Tang, M., & Runco, M. A. (2020). Approach motivational orientation enhances malevolent creativity. *Acta Psychologica*, *203*, 102985. https://doi.org/10.1016/j.actpsy.2019.102985

Hao, N., Tang, M., Yang, J., Wang, Q., & Runco, M. A. (2016). A new tool to measure malevolent creativity: The malevolent creativity behavior scale. *Frontiers in Psychology*, *7*, 00682. https://doi.org/10.3389/fpsyg.2016.00682

Hao, N., Xue, H., Yuan, H., Wang, Q., & Runco, M. A. (2017). Enhancing creativity: Proper body posture meets proper emotion. *Acta Psychologica*, *173*, 32–40. https://doi.org/10.1016/j.actpsy.2016.12.005

Harenski, C. L., Antonenko, O., Shane, M. S., & Kiehl, K. A. (2010). A functional imaging investigation of moral deliberation and moral intuition. *NeuroImage*, *49*(3), 2707–2716. https://doi.org/10.1016/j.neuroimage.2009.10.062

Harris, D. J., & Reiter-Palmon, R. (2015). Fast and furious: The influence of implicit aggression, premeditation, and provoking situations on malevolent creativity. *Psychology of Aesthetics, Creativity, and the Arts*, *9*(1), 54–64. https://doi.org/10.1037/a0038499

Harris, D. J., Reiter-Palmon, R., & Kaufman, J. C. (2013). The effect of emotional intelligence and task type on malevolent creativity. *Psychology of Aesthetics, Creativity, and the Arts*, *7*(3), 237–244. https://doi.org/10.1037/a0032139

Heinonen, J., Numminen, J., Hlushchuk, Y., Antell, H., Taatila, V., Suomala, J., & Stamatakis, E. A. (2016). Default mode and executive networks areas: Association with the serial order in divergent thinking. *PLoS ONE*, *11*(9), e0162234. https://doi.org/10.1371/journal.pone.0162234

Hu, Y., Hu, Y., Li, X., Pan, Y., & Cheng, X. (2017). Brain-to-brain synchronization across two persons predicts mutual prosociality. *Social Cognitive and Affective Neuroscience*, *12*(12), 1835–1844. https://doi.org/10.1093/scan/nsx118

Jang, K. E., Tak, S., Jung, J., Jang, J., Jeong, Y., & Ye, J. C. (2009). Wavelet minimum description length detrending for near-infrared spectroscopy. *Journal of Biomedical Optics*, *14*(3), 034004. https://doi.org/10.1117/1.3127204

Jonason, P. K., Abboud, R., Tomé, J., Dummett, M., & Hazer, A. (2017). The Dark Triad traits and individual differences in self-reported and other-rated creativity. *Personality and Individual Differences*, *117*, 150–154. https://doi.org/10.1016/j.paid.2017.06.005

Kana, R. K., Sartin, E. B., Stevens, C., Deshpande, H. D., Klein, C., Klinger, M. R., & Klinger, L. G. (2017). Neural networks underlying language and social cognition during self-other processing in autism spectrum disorders. *Neuropsychologia*, *102*, 116–123. https://doi.org/10.1016/j.neuropsychologia.2017.06.008

Keuken, M. C., Hardie, A., Dorn, B. T., Dev, S., Paulus, M. P., Jonas, K. J., Den Wildenberg, W. P. M. V., & Pineda, J. A. (2011). The role of the left inferior frontal gyrus in social perception: An rTMS study. *Brain Research*, *1383*, 196–205. https://doi.org/10.1016/j.brainres.2011.01.073

Khorakian, A., Hemsworth, D., Jahangir, M., Maharati, Y., Bagherpour, E. S., & Muterera, J. (2020). The effects of religious orientations on malevolent creativity: Role of positive emotions and spiritual intelligence. *Creativity Research Journal*, *32*(4), 421–430. https://doi.org/10.1080/10400419.2020.1818491

Lee, K., & Ashton, M. C. (2004). Psychometric properties of the HEXACO personality inventory. *Multivariate Behavioral Research*, *39*(2), 329–358. https://doi.org/10.1207/s15327906mbr3902_8

Lee, S. A., & Dow, G. T. (2011). Malevolent creativity: Does personality influence malicious divergent thinking? *Creativity Research Journal*, *23*(2), 73–82. https://doi.org/10.1080/10400419.2011.571179

Lu, K., Qiao, X., & Hao, N. (2019). Praising or keeping silent on partner's ideas: Leading brainstorming in particular ways. *Neuropsychologia*, *124*, 19–30. https://doi.org/10.1016/j.neuropsychologia.2019.01.004

Lu, F., Wang, M., Xu, S., Chen, H., Yuan, Z., Luo, L., , and Zhou, J. (2020). Decreased interhemispheric resting-state functional connectivity in male adolescents with conduct disorder. *Brain Imaging and Behavior*, *15*, 1–10. https://doi.org/10.1007/s11682-020-00320-8

Lu, K., Xue, H., Nozawa, T., & Hao, N. (2019b). Cooperation makes a group be more creative. *Cerebral Cortex*, *29*(8), 3457–3470. https://doi.org/10.1093/cercor/bhy215

Lu, C.-M., Zhang, Y.-J., Biswal, B. B., Zang, Y.-F., Peng, D.-L., & Zhu, C.-Z. (2010). Use of fNIRS to assess resting state functional connectivity. *Journal of Neuroscience Methods*, *186*(2), 242–249. https://doi.org/10.1016/j.jneumeth.2009.11.010

Lu, F., Zhou, J., Wang, X., Xiang, Y., & Yuan, Z. (2017). Short- and long-range functional connectivity density alterations in adolescents with pure conduct disorder at resting-state. *Neuroscience*, *351*, 96–107. https://doi.org/10.1016/j.neuroscience.2017.03.040

McLaren, R. B. (1993). The dark side of creativity. *Creativity Research Journal*, *6*(1–2), 137–144. https://doi.org/10.1080/10400419309534472

Pan, Y., Novembre, G., Song, B., Li, X., & Hu, Y. (2018). Interpersonal synchronization of inferior frontal cortices tracks social interactive learning of a song. *NeuroImage*, *183*, 280–290. https://doi.org/10.1016/j.neuroimage.2018.08.005

Paulhus, D. L., & Williams, K. M. (2002). The dark triad of personality: Narcissism, machiavellianism, and psychopathy. *Journal of Research in Personality*, *36*(6), 556–563. https://doi.org/10.1016/S0092-6566(02)00505-6

Perchtold-Stefan, C. M., Fink, A., Rominger, C., & Papousek, I. (2020). Creative,antagonistic, and angry? exploring the roots of malevolent creativity with a Real-World idea generation task. *The Journal of Creative Behavior*, *55*(3), 710–722. https://doi.org/10.1002/jocb.484

Quan, F., Zhu, W., Dong, Y., Qiu, J., Gong, X., Xiao, M., Zheng, Y., Zhao, Y., Chen, X., & Xia, L.-X. (2019). Brain structure links trait hostile attribution bias and attitudes toward violence. *Neuropsychologia*, *125*, 42–50. https://doi.org/10.1016/j.neuropsychologia.2019.01.015

Runco, M. A., & Acar, S. (2012). Divergent thinking as an indicator of creative potential. *Creativity Research Journal*, *24*(1), 66–75. https://doi.org/10.1080/10400419.2012.652929

Runco, M. A., Alabbasi, A. M. A., Paek, S. H., Alsuwaidi, H. N., & Alsuwaidi, H. N. (2016). Which test of divergent thinking is best? *Creativity: Theories-Research-Applications*, *3*(1), 4–18. https://doi.org/10.1515/ctra-2016-0001

Runco, M. A., & Mraz, W. (1992). Scoring divergent thinking tests using total ideational output and a creativity index. *Educational and Psychological Measurement*, *52*(1), 213–221. https://doi.org/10.1177/001316449205200126

Runco, M. A., & Okuda, S. M. (1991). The instructional enhancement of the flexibility and originality scores of divergent thinking tests. *Applied Cognitive Psychology*, *5*(5), 435–441. https://doi.org/10.1002/acp.2350050505

Sai, L., Zhou, X., Ding, X. P., Fu, G., & Sang, B. (2014). Detecting concealed information using functional near-infrared spectroscopy. *Brain Topography*, *27*(5), 652–662. https://doi.org/10.1007/s10548-014-0352-z

Schecklmann, M., Ehlis, A. C., Plichta, M. M., & Fallgatter, A. J. (2010). Influence of muscle activity on brain oxygenation during verbal fluency assessed with functional near-infrared spectroscopy. *Neuroscience*, *171*(2), 434–442. https://doi.org/10.1016/j.neuroscience.2010.08.072

Singh, A. K., Okamoto, M., Dan, H., Jurcak, V., & Dan, I. (2005). Spatial registration of multichannel multi-subject fNIRS data to MNI space without MRI. *NeuroImage*, *27*(4), 842–851. https://doi.org/10.1016/j.neuroimage.2005.05.019

Sternberg, R. J., & Lubart, T. I. (1996). Investing in creativity. *American Psychologist*, *51*(7), 677–688. https://doi.org/10.1037/0003-066X.51.7.677

Takeuchi, N., Mori, T., Suzukamo, Y., & Izumi, S. I. (2019). Activity of prefrontal cortex in teachers and students during teaching of an insight problem. *Mind, Brain, and Education*, *13*(3), 167–175. https://doi.org/10.1111/mbe.12207

Tempest, G. D., & Radel, R. (2019). Put on your (fNIRS) thinking cap: Frontopolar activation during augmented state creativity. *Behavioural Brain Research*, *373*, 112082. https://doi.org/10.1016/j.bbr.2019.112082

Tong, Y., Lindsey, K. P., & deB Frederick, B. (2011). Partitioning of physiological noise signals in the brain with concurrent near-infrared spectroscopy and fMRI. *Journal of Cerebral Blood Flow & Metabolism*, *31*(12), 2352–2362. https://doi.org/10.1038/jcbfm.2011.100

Tsuzuki, D., Jurcak, V., Singh, A. K., Okamoto, M., Watanabe, E., & Dan, I. (2007). Virtual spatial registration of stand-alone fNIRS data to MNI space. *NeuroImage*, *34*(4), 1506–1518. https://doi.org/10.1016/j.neuroimage.2006.10.043

Van Goozen, S. H., & Fairchild, G. (2006). Neuroendocrine and neurotransmitter correlates in children with antisocial behavior. *Hormones and Behavior*, *50*(4), 647–654. https://doi.org/10.1016/j.yhbeh.2006.06.021

Wang, M., Hao, N., Ku, Y., Fink, A., & Fink, A. (2017). Neural correlates of serial order effect in verbal divergent thinking. *Neuropsychologia*, *99*, 92–100. https://doi.org/10.1016/j.neuropsychologia.2017.03.001

Wood, J. N., Romero, S. G., Makale, M., & Grafman, J. (2003). Category-specific representations of social and nonsocial knowledge in the human prefrontal cortex. *Journal of Cognitive Neuroscience*, *15*(2), 236–248. https://doi.org/10.1162/089892903321208178

Wu, X., Yang, W., Tong, D., Sun, J., Chen, Q., Wei, D., Zhang, Q., Zhang, M., & Qiu, J. (2015). A meta-analysis of neuroimaging studies on divergent thinking using activation likelihood estimation. *Human Brain Mapping*, *36*(7), 2703–2718. https://doi.org/10.1002/hbm.22801

Xue, H., Lu, K., & Hao, N. (2018). Cooperation makes two less-creative individuals turn into a highly-creative pair. *NeuroImage*, *172*, 527–537. https://doi.org/10.1016/j.neuroimage.2018.02.007

Yang, J., Zhang, H., Ni, J., De Dreu, C. K. W., & Ma, Y. (2020). Within-group synchronization in the prefrontal cortex associates with intergroup conflict. *Nature Neuroscience*, *23*(6), 754–760. https://doi.org/10.1038/s41593-020-0630-x

Ye, J. C., Tak, S., Jang, K. E., Jung, J., & Jang, J. (2009). NIRS-SPM: Statistical parametric mapping for near-infrared spectroscopy. *NeuroImage*, *44*(2), 428–447. https://doi.org/10.1016/j.neuroimage.2008.08.036

Zahn, R., Moll, J., Krueger, F., Huey, E. D., Garrido, G., & Grafman, J. (2007). Social concepts are represented in the superior anterior temporal cortex. *Proceedings of the National Academy of Sciences*, *104*(15), 6430–6435. https://doi.org/10.1073/pnas.0607061104

Zhang, X., Noah, J. A., & Hirsch, J. (2016). Separation of the global and local components in functional near-infrared spectroscopy signals using principal component spatial filtering. *Neurophotonics*, *3*(1), 015004. https://doi.org/10.1117/1.nph.3.1.015004

Zhu, W., Chen, Q., Xia, L., Beaty, R. E., Yang, W., Tian, F., Qiu, J., Cao, G., Zhang, Q., Chen, X., & Qiu, J. (2017). Common and distinct brain networks underlying verbal and visual creativity. *Human Brain Mapping*, *38*(4), 2094–2111. https://doi.org/10.1002/hbm.23507

Zhu, L., Jenkins, A. C., Set, E., Scabini, D., Knight, R. T., Chiu, P. H., King-Casas, B., & Hsu, M. (2014). Damage to dorsolateral prefrontal cortex affects tradeoffs between honesty and self-interest. *Nature Neuroscience*, *17*(10), 1319–1321. https://doi.org/10.1038/nn.3798

Appendix

Table S1. Original and Translated Versions of Malevolent Creativity Task.

Malevolent Creativity Task (MCT)	
Chinese Version	English Version
(1) 你一位讨厌撞衫的朋友发现有同学的外套和他一样。替他想一个可以暗中毁掉同学外套的新颖办法。	(1) One of your friends who hates dress alike with others finds that a classmate wearing a same coat as him. Please generate a novel way for him to secretly damage his classmate's coat.
(2) 小红很想要隔壁宿舍同学的限量版专辑, 请想一个可以让小红偷走限量版专辑的新颖方案。	(2) Hong really desires the limited-edition album belonging to the neighbor classmate. Please generate a novel way for Hong to steal the album.
(3) 小明想在期末考试的时候名列前茅, 请想一个可以让小明干扰同学复习的新颖办法。	(3) Ming wants to perform best in the final exam. Please generate a novel way for Ming to Disturb other students' review.
(4) 某球迷得到了一件敌方球队的球衣。请帮该球迷想一个毁掉球衣的新颖方法, 进而打击对手士气。	(4) A soccer fan got a opposite team's jersey. Please generate a novel way for the fan to destroy the jersey, and undermine the morale of the opposite team.
(5) 小明很讨厌的一位校领导的照片被贴在了公告栏。想一个新颖的办法让小明可以暗中毁掉照片。	(5) A picture of a school leader whom Ming hated was posted on the bulletin board. Please generate a novel way for Ming that he can secretly destroy the photo.
(6) 小红暗恋一个人很久, 此时却突然出现了情敌。替小红想一个破坏情敌形象的新颖方法。	(6) Hong has a crush on someone for a long time, but a rival suddenly appeared. Please generate a novel way for Hong to ruin her rival's reputation.
(7) 小红不爽舍友总是说自己的母校好。替小红想一个新颖的方法让舍友被其他同学排挤。	(7) Hong is dissatisfied with her roommate who always said that she come from a famous school. Please generate a novel way for Hong to make her roommate be excluded by others.
(8) 你朋友抱怨他对面宿舍门上贴了他很讨厌的画。替他想一个新颖的方法逼对面的人把画撕掉。	(8) Your friend is complaining about the disgusting painting posted on the door of the opposite dormitory. Please generate a novel way for him to force the residents in the opposite dormitory to tear up the painting.
(9) 小明不满舍友总是抽比自己好的烟。替小明想一个新颖的办法, 在舍友烟上做手脚让他不敢再吸。	(9) Ming is dissatisfied that his roommate always smokes better cigarettes than himself. Please generate a novel way for him to do some tricks on his roommate's cigarettes so that his roommate dares not smoke anymore.
(10) 小明很不爽隔壁班的人中午下课比自己早。替小明想一个新颖的办法让隔壁班的人无法按时下课。	(10) Ming is very annoying that other schoolfellows finish their class earlier at noon. Please generate a novel way for Ming to prevent schoolfellows from finishing their class on time.
(11)小红不想让喜欢的男生到外地读研, 替小红想一个新颖的办法让该男生考研失败。	(11) Hong doesn't want the boy she likes to pursuit master degree in another city. Please generate a novel way for Hong to make the boy fail the entrance examination.
(12) 小明学校的篮球队很自大, 喜欢到处乱贴队徽。替小明想一个新颖的办法让该队徽沦为笑柄。	(12) The basketball team of Ming's school is very arrogant and likes to stick the team badges everywhere. Please generate a novel way for Ming to turn the team badge into a laughing stock.
(13) 小明弄坏了投影仪, 但不想被揭穿。想一个新颖的办法, 让小明可以把这件事栽赃给他的同学。	(13) Ming broke the projector, but didn't want to be discovered. Please generate a novel way for Ming to plant this incident on his classmates.
(14) 小红不小心把室友的银行卡折断了。想一个新颖的办法, 让小红可以隐瞒这件事。	(14) Hong accidentally broke her roommate's bank card. Please generate a novel way for Hong to conceal this accident.
(15) 由于小明忘记保存, 导致小组作业无法按时提交。想一个新颖的办法让小明可以逃脱责任。	(15) The group work could not be submitted on time because Ming forgot to save it. Please generate a novel way for Ming to escape responsibility.

Table S2. Original and Translated Versions of Benevolent Creativity Task.

Benevolent Creativity Task (BCT)			
	Chinese Version		English Version
(1)	有位女士的高跟鞋鞋跟断了, 走不了路。但她急着参加一个会议, 请想一个新颖的办法帮助她。	(1)	A lady has broken her high-heeled shoes and she can't walk. But she is anxious to attend a meeting. Please generate a novel way to help her.
(2)	小明因为生病错过了偶像的演唱会, 情绪很低落。请想一个新颖的办法帮小明补偿他的遗憾。	(2)	Ming missed his idol's concert because of physically unwell, and he felt very depressed. Please generate a novel way to compensate his regrets.
(3)	你的朋友因为害怕坐过山车, 而觉得自己很没用。请想一个新颖的方法帮他重拾自信。	(3)	Your friend feels that he is useless because he is afraid of riding a roller coaster. Please generate a novel way to regain his confidence.
(4)	住你隔壁的老爷爷总是把钥匙插在门上忘了拔。请你想一个新颖的方法, 可以一直提醒他拔钥匙。	(4)	Your neighbor is an old man who always puts the key in the door and forgets to pull it out. Please generate a novel way to keep reminding him to pull out the key.
(5)	你朋友要进行期末PPT演讲。但他遇上堵车, 无法及时赶到。请你帮他想一个新颖的补救方法。	(5)	Your friend is about to give a presentation using Microsoft PowerPoint. However, he cannot be present on time because of a traffic jam. Please generate a novel remedy to help him.
(6)	小明所在地区附近发生地震, 而他正在电影院看电影, 请想一个新颖办法让小明帮助更多人逃生。	(6)	An earthquake occurs near the area where Ming is, and he is watching a movie in the cinema. Please generate a novel way that Ming can evacuate more people.
(7)	你的好朋友要做一场学术报告, 报告开始前, 发现带错了PPT, 请想一个帮他解围的新颖方法。	(7)	Your good friend is going to do an academic report. Before the report started, he notices that he has brought the wrong PowerPoint document. Please generate a novel way to help him out.
(8)	你同学的家人生病急需钱。请想一个新颖的办法帮他筹集治疗费, 又不让他觉得有负担。	(8)	One of your classmate's family members is ill and your classmate needs money urgently. Please generate a novel way to help him raise treatment cost without making him feel burdened.
(9)	你朋友很害羞, 不敢主动认识暗恋的对象。请想出一个新颖方法帮他去自然的认识对方。	(9)	Your friend is very shy and dare not take the initiative to meet the girl he likes. Please generate a novel way to help him to know the girl naturally.
(10)	因为改建, 人们不愿意绕路来吃饭, 饭店生意一落千丈。请想一个新颖的办法帮老板改善生意。	(10)	After Urban reconstruction, the restaurant business is plummeted because customers are unwilling to take a detour. Please generate a novel way to help the owner improve his business.
(11)	情人节已过, 花店老板的玫瑰花卖不出去。请帮老板想一个把玫瑰花存货卖掉的新颖办法。	(11)	Valentine's Day has passed, and the roses cannot be sold out. Please generate a novel way to help the owner to sell the remaining roses.
(12)	小红有一件衣服买大了, 身边没有人愿意要, 又无法退货。请帮她想一个新颖的办法挽回损失。	(12)	Hong has brought a poor-fitting dress. None of her friend wants to take it and Hong can't refund it. Please generate a novel way to help Hong recover her financial loss.
(13)	小明把小时候爷爷送给他的钥匙扣弄断了, 很伤心。请想一个新颖的方法, 帮他找到一个替代品。	(13)	Ming has broken the keychain that his grandfather gave him when he was a child, and he was very sad. Please generate a novel way to help him find a substitute.
(14)	小红毕业后要离开这座城市回到家乡, 她想带走一些东西作纪念。请帮她挑选一个新颖的纪念品。	(14)	A historical monument was sprayed with paint, and the administrator was very distressed. Please generate a novel way to arouse people's respect for this period of history.
(15)	一座历史纪念碑被乱喷颜料, 管理员很苦恼。帮他想一个新颖的办法, 唤起人们对这段历史的尊重。	(15)	After graduating, Hong will leave this city and return to her hometown. She wants to take something as a souvenir. Please help her choose a novel souvenir.

Table S3. Original and Translated Versions of Alternative Use Task.

Alternative Use Task (AUT)	
Chinese Version	English Version
(1) 假设现在你有一张CD唱片，请在它的常规用途之外，为这张CD唱片想一个与众不同的新颖用法。	(1) Please generate a novel use for “CD” (Compact Disk).
(2) 假设现在你有一根电线，请在它的常规用途之外，为这根电线想一个与众不同的新颖用法。	(2) Please generate a novel use for “electric wire”.
(3) 假设现在你有一条皮带，请在它的常规用途之外，为这条皮带想一个与众不同的新颖用法。	(3) Please generate a novel use for “belt”.
(4) 假设现在你有一张报纸，请在它的常规用途之外，为这张报纸想一个与众不同的新颖用法。	(4) Please generate a novel use for “newspaper”.
(5) 假设现在你有一个纸杯，请在它的常规用途之外，为这个纸杯想一个与众不同的新颖用法。	(5) Please generate a novel use for “paper cup”.
(6) 假设现在你有一颗纽扣，请在它的常规用途之外，为这颗纽扣想一个与众不同的新颖用法。	(6) Please generate a novel use for “button”.
(7) 假设现在你有一个矿泉水瓶，请在它的常规用途之外，为这个矿泉水瓶想一个与众不同的新颖用法。	(7) Please generate a novel use for “plastic bottle”.
(8) 假设现在你有一块砖头，请在它的常规用途之外，为这块砖头想一个与众不同的新颖用法。	(8) Please generate a novel use for “brick”.
(9) 假设现在你有一张信用卡，请在它的常规用途之外，为这张信用卡想一个与众不同的新颖用法。	(9) Please generate a novel use for “credit card”.
(10) 假设现在你有一个信封，请在它的常规用途之外，为这个信封想一个与众不同的新颖用法。	(10) Please generate a novel use for “envelope”.
(11) 假设现在你有一支铅笔，请在它的常规用途之外，为这支铅笔想一个与众不同的新颖用法。	(11) Please generate a novel use for “pencil”.
(12) 假设现在你有一个盘子，请在它的常规用途之外，为这个盘子想一个与众不同的新颖用法。	(12) Please generate a novel use for “plate”.
(13) 假设现在你有一双筷子，请在它的常规用途之外，为这双筷子想一个与众不同的新颖用法。	(13) Please generate a novel use for “chopsticks”.
(14) 假设现在你有一个塑料袋，请在它的常规用途之外，为这个塑料袋想一个与众不同的新颖用法。	(14) Please generate a novel use for “plastic bag”.
(15) 假设现在你有一个螺丝刀，请在它的常规用途之外，为这个螺丝刀想一个与众不同的新颖用法。	(15) Please generate a novel use for “screw driver”.

Table S4. Results of Linear Mixed Model on Beta Increment.

Variables	*F*-values
	CH29
Task	5.09**
Anxiety	1.56
Pleasure	1.32

$p < .05$ *; $p < .01$ **; $p < .001$ ***

Table S5. Results of Linear Mixed Model on NC Increment.

Variables	*F*-values			
	CH3-CH17	CH8-CH22	CH7-CH36	CH12-CH36
Task	8.16***	6.01**	10.54***	11.93***
Anxiety	.46	.68	5.49*	10.07**
Pleasure	.36	1.36	.02	1.58

$p < .05$ *; $p < .01$ **; $p < .001$ ***