

Semantic associations and executive control predict Novelty and appropriateness of idea generation respectively and mediated by separate brain connectivity

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Table S1. Results of general linear models predicting novelty and appropriateness after controlling for gender, age and handedness. In bold are correlations that reached significance after FWE correction for multiple comparisons.

	Novelty				Appropriateness			
	β	<i>s.e.</i>	<i>t</i>	<i>p</i>	β	<i>s.e.</i>	<i>t</i>	<i>p</i>
Associative ability	0.12	0.03	4.57	< 0.001	-0.04	0.03	-1.67	> 0.05
Executive function	-0.03	0.03	-1.11	> 0.05	-0.08	0.04	-2.98	0.012

Table S2. The specific functional neuroanatomical basis for novelty derived from rs-fMRI (BBP dataset).

Behavioral outcomes	Sample size	<i>r</i>	η^2
RRS_RP_Score	1438	-7.43E-05	5.520E-09
NEO_C_Score	1411	3.10E-03	9.623E-06
RRS_Score	1438	-3.51E-03	1.230E-05
CTQ_SFca_Score	1438	4.04E-03	1.629E-05
SWB_Score	1438	4.07E-03	1.657E-05
CFS_EC_Score	1438	-4.29E-03	1.843E-05
ANT_O_RT	1416	-4.98E-03	2.475E-05
CFS_AC_Score	1438	-6.10E-03	3.716E-05
POMS_V_Score	1438	6.40E-03	4.092E-05
NEO_E_Score	1411	6.70E-03	4.488E-05
CTQ_SF_Score	1438	7.47E-03	5.579E-05
SRS_ES_Score	1438	7.96E-03	6.334E-05
SRS_IS_Score	1438	-8.27E-03	6.840E-05
POMS_E_Score	1438	-8.57E-03	7.343E-05
SRS_L_Score	1438	9.23E-03	8.524E-05
POMS_C_Score	1438	-1.04E-02	1.073E-04
BIS_Score	1446	-1.05E-02	1.099E-04
POMS_A_Score	1438	-1.09E-02	1.191E-04
PANAS_NA_Score	1447	1.10E-02	1.212E-04
SSCS_CSE_Score	1438	1.19E-02	1.411E-04
NEO_N_Score	1411	1.22E-02	1.495E-04
CTQ_SFpa_Score	1438	1.32E-02	1.731E-04
CTQ_SFpn_Score	1438	-1.39E-02	1.931E-04
PANAS_PA_Score	1447	1.40E-02	1.948E-04
RRS_B_Score	1438	1.53E-02	2.340E-04
CEI-II_Score	1438	1.64E-02	2.701E-04
SRS_F_Score	1438	-1.65E-02	2.733E-04
ERQ_CR_Score	1446	1.65E-02	2.739E-04
SP_Score	1421	-1.67E-02	2.782E-04
PSS_Score	1446	1.72E-02	2.943E-04
Grit_S_PE_Score	1446	-2.34E-02	5.461E-04
SRS_PH_Score	1438	-2.47E-02	6.117E-04
ASLEC_Score	1446	-2.51E-02	6.279E-04
BIS_MI_Score	1446	-2.52E-02	6.350E-04
SPQ_B_Score	1438	-2.60E-02	6.739E-04
Grit_S_CI_Score	1446	2.60E-02	6.785E-04
NEO_A_Score	1411	-2.72E-02	7.385E-04
SRS_PR_Score	1438	-2.73E-02	7.435E-04

Behavioral outcomes	Sample size	<i>r</i>	η^2
ANT_A_RT	1416	2.73E-02	7.476E-04
BIS_BAS_I_Score	1446	-2.81E-02	7.885E-04
SR_Score	1421	2.85E-02	8.144E-04
BIS_nPI_Score	1446	2.90E-02	8.431E-04
CD_RISC_Score	1438	-2.98E-02	8.853E-04
NFC_Score	1438	3.04E-02	9.228E-04
BIS_AI_Score	1446	-3.06E-02	9.381E-04
PSQI_Score	1417	3.23E-02	1.044E-03
SWLS_Score	1438	-3.28E-02	1.073E-03
SDS_Score	1438	-3.32E-02	1.103E-03
POMS_D_Score	1438	-3.40E-02	1.157E-03
CTQ_SFen_Score	1438	3.49E-02	1.216E-03
STAI_T_Score	817	-3.87E-02	1.497E-03
ERQ_ES_Score	1446	-4.02E-02	1.615E-03
CTQ_SFsa_Score	1438	-4.32E-02	1.870E-03
POMS_T_Score	1438	-4.61E-02	2.122E-03
POMS_F_Score	1438	4.74E-02	2.248E-03
BIS_BAS_A_Score	1446	-4.87E-02	2.370E-03
ANT_C_RT	1416	-5.69E-02	3.236E-03
SSCS_CPI_Score	1438	5.74E-02	3.292E-03
RAPM_Score	1417	7.82E-02	6.109E-03
NEO_O_Score	1411	9.88E-02	9.760E-03
Novelty_Score	1455	4.75E-01	2.256E-01

Table S3. The specific functional neuroanatomical basis for appropriateness derived from rs-fMRI (BBP dataset).

Behavioral outcomes	Sample size	<i>r</i>	η^2
CD_RISC_Score	1438	3.51E-04	1.23E-07
POMS_E_Score	1438	-3.99E-04	1.59E-07
POMS_F_Score	1438	7.87E-04	6.19E-07
POMS_A_Score	1438	1.32E-03	1.74E-06
CTQ_SFpa_Score	1438	1.81E-03	3.27E-06
BIS_nPI_Score	1446	-3.73E-03	1.39E-05
POMS_D_Score	1438	-4.12E-03	1.69E-05
POMS_C_Score	1438	4.20E-03	1.76E-05
ANT_A_RT	1416	4.43E-03	1.96E-05
SRS_PR_Score	1438	-4.45E-03	1.98E-05
BIS_BAS_I_Score	1446	4.75E-03	2.26E-05
NEO_N_Score	1411	-5.53E-03	3.05E-05
POMS_T_Score	1438	7.05E-03	4.98E-05
ERQ_ES_Score	1446	-7.11E-03	5.06E-05
CEI-II_Score	1438	-8.15E-03	6.63E-05
ASLEC_Score	1446	-9.56E-03	9.14E-05
POMS_V_Score	1438	-9.89E-03	9.78E-05
PANAS_NA_Score	1447	-1.03E-02	1.06E-04
Grit_S_PE_Score	1446	1.07E-02	1.14E-04
RAPM_Score	1417	-1.07E-02	1.14E-04
SRS_F_Score	1438	-1.07E-02	1.15E-04
BIS_AI_Score	1446	1.07E-02	1.15E-04
NFC_Score	1438	1.07E-02	1.16E-04
PSS_Score	1446	-1.10E-02	1.22E-04
STAI_T_Score	817	-1.15E-02	1.33E-04
SWLS_Score	1438	-1.19E-02	1.41E-04
CTQ_SFsa_Score	1438	1.24E-02	1.53E-04
SPQ_B_Score	1438	-1.26E-02	1.59E-04
SWB_Score	1438	1.52E-02	2.30E-04
CTQ_SFpn_Score	1438	-1.58E-02	2.51E-04
NEO_E_Score	1411	-1.62E-02	2.62E-04
SRS_IS_Score	1438	-1.71E-02	2.93E-04
BIS_Score	1446	-1.99E-02	3.94E-04
SRS_L_Score	1438	-2.06E-02	4.24E-04
ANT_C_RT	1416	2.19E-02	4.78E-04
NEO_O_Score	1411	-2.24E-02	5.01E-04
RRS_B_Score	1438	2.27E-02	5.17E-04
CTQ_SF_Score	1438	-2.65E-02	7.02E-04
ANT_O_RT	1416	-2.73E-02	7.46E-04

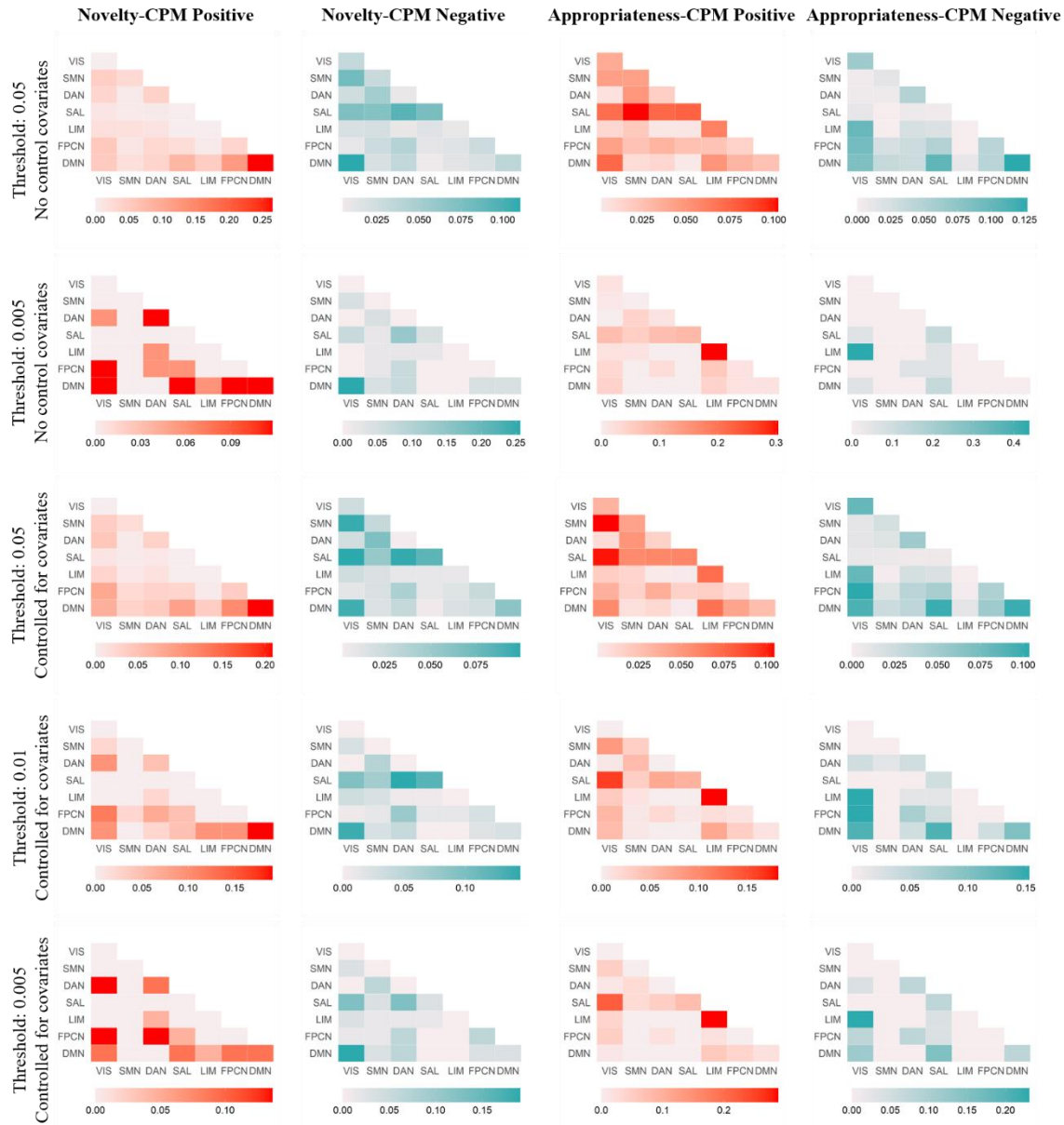
Behavioral outcomes	Sample size	<i>r</i>	η^2
SRS_ES_Score	1438	-2.83E-02	8.02E-04
ERQ_CR_Score	1446	-2.92E-02	8.52E-04
CTQ_SFes_Score	1438	-3.06E-02	9.37E-04
Grit_S_CI_Score	1446	-3.19E-02	1.02E-03
NEO_A_Score	1411	3.20E-02	1.03E-03
CFS_AC_Score	1438	-3.30E-02	1.09E-03
NEO_C_Score	1411	3.37E-02	1.14E-03
SP_Score	1421	3.51E-02	1.23E-03
SSCS_CSE_Score	1438	-3.53E-02	1.25E-03
SRS_PH_Score	1438	-3.62E-02	1.31E-03
PANAS_PA_Score	1447	-3.65E-02	1.33E-03
CTQ_SFen_Score	1438	-3.88E-02	1.51E-03
SR_Score	1421	-4.35E-02	1.89E-03
BIS_MI_Score	1446	-4.85E-02	2.35E-03
BIS_BAS_A_Score	1446	4.98E-02	2.48E-03
PSQI_Score	1417	-5.05E-02	2.55E-03
SDS_Score	1438	5.27E-02	2.78E-03
RRS_RP_Score	1438	6.19E-02	3.84E-03
SSCS_CPI_Score	1438	-6.27E-02	3.93E-03
RRS_Score	1438	6.34E-02	4.02E-03
CFS_EC_Score	1438	1.39E-01	1.94E-02
Appropriateness_Score	1455	5.25E-01	2.76E-01

Table S4. Objects presented in each trial of task-fMRI.

		NU	GC
Block 1	Trial 1-4	Coin Compact disc	Ruler Pillow
Block 2	Trial 5-10	Gloves Eraser Watermelon	Curtain Writing brush Comb
Block 3	Trial 11-16	Walnut Hair Bamboo	Clip Water bottle Windmill
Block 4	Trial 17-22	Calendar Stapler Chinese cabbage	Key Fan Coat hanger

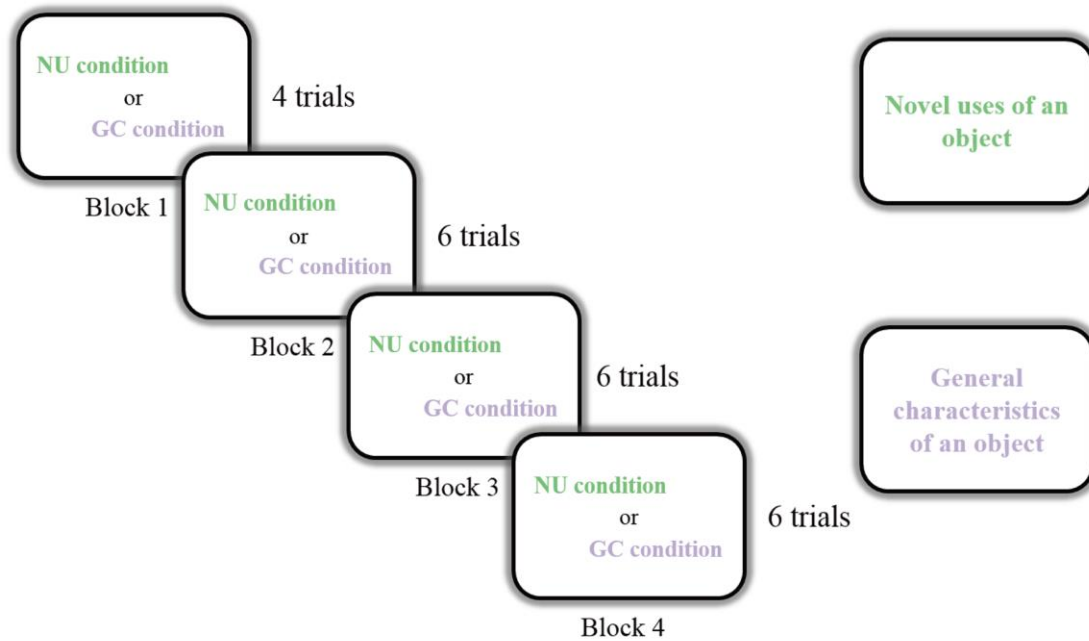
SI Supplementary Figures

Supplementary Figure S1



Supplementary Figure S1. Functional neuroanatomical basis of the Novelty-CPM and Appropriateness-CPM network. The percentage of number of edges, among those within the Novelty-CPM or Appropriateness-CPM mask, assigned to each within- or between-network pair based on the Schaefer300 and Yeo-Krienen 7-network atlases. Each column from left to right is Novelty-CPM positive mask, Novelty-CPM negative mask, Appropriateness-CPM positive mask and Appropriateness-CPM negative mask. Each row from top to bottom is the result of 5 different CPM models. DAN dorsal attention network, DMN default mode network, FPCN frontoparietal control network; LIM limbic network, SAL salience network, SMN sensorimotor network, TP temporal-parietal network, VIS visual network, CPM connectome-based predictive model.

Supplementary Figure S2



Supplementary Figure S2. Task-fMRI of Alternative Uses Task. NU Novelty Use; GC General Characteristic.

SI Supplementary text

Material and Methods.

Behavioral and self-report measures (BBP dataset)

Ruminative Responses Scale (RRS)

The RRS contains 22 items that were rated on a 1-4 scale ('almost never' to 'almost always')¹ and was used to measure Rumination. The RRS is comprised of three subscales: reflective pondering, brooding and depression. We dismissed the depression domain due to extant research demonstrating spuriously discriminant validity with the overlapping portions across depressive symptoms². Thereby, the current work used reflective pondering score (RRS_RP_Score) and brooding score (RRS_B_Score), and summed them to represent the total rumination score (RRS_Score). The internal consistency of the RSS was 0.92³.

Attention Network Task (ANT)

The ANT^{4,5} requires the participant to determine whether the middle arrow of 5 side-by-side arranged arrows points left or right. Participants were instructed to press "F" when middle arrow points left and to press "J" when middle arrow points right. A session consisted of a 24-trial practice block and two experimental blocks. Each experimental block consisted of 48 trials (4 cue conditions × 2 target locations × 2 target directions × 3 flanker conditions). In the present study, stimulus setup and presentation of ANT were the same as ref.⁴, see ref.⁴ for details of stimulus setup and presentation. RT of alerting (ANT_A_RT), orienting (ANT_O_RT) and conflict (ANT_C_RT) were used in the current work.

State-Trait Anxiety Inventory (STAI)

The STAI⁶ consists of 20 items that assess an individual's feelings over the past week (the state scale of STAI [STAI-S]) and 20 other items that assess an individual's general feelings (the trait scale of STAI [STAI-T]) based on a 4-point Likert scale. The current research measured the trait anxiety (STAI_T_Score) of participants using STAI-T.

Ravens Advanced Progressive Matrices (RAPM)

The RAPM is composed of 48 nonverbal picture items. The 48 items can be subdivided in one set of 12 items (set I) and another set of 36 items (set II)⁷. Fluid intelligence was measured by set II of RAPM in the current work and participants were asked to complete it within 40 minutes. The index of fluid intelligence (RAPM_Score) was calculated as the total number of correct answers.

Positive and negative affect scale (PANAS)

The PANAS⁸ is a self-report questionnaire that consists of 10 items to measure positive affect and another 10 items to measure negative affect. Each item is rated on a 5-point scale of 1 (not at all) to 5 (very much). The total score of positive effects (PANAS_PA_Score) and total score of negative effects (PANAS_NA_Score) were used in the current research.

Profile of Mood States (POMS)

The current study used the 40-item version of POMS ⁹. The POMS is a psychological rating scale used to assess transient, distinct mood states based on a 5-point Likert scale (1 = not at all and 5 = extremely). The scale measures 7 different dimensions of mood swings over a period of time. These include: tension (POMS_T_Score), depression (POMS_D_Score), fatigue (POMS_F_Score), vigor (POMS_V_Score), confusion (POMS_C_Score), anger (POMS_A_Score), and esteem-related affect (POMS_E_Score). These 7 scores were used in the current work.

Self-rating depression scale (SDS)

The SDS ¹⁰ contains 20 items that assess an individual's depressed feelings over the past week based on a 4-point Likert scale. The total score of SDS (SDS_Score) was used in the current research.

Barratt Impulsiveness Scale (BIS)

The BIS ¹¹ is a 30-item self-report measure. Items are scored on a 4-point Likert scale from 1 (rarely/never) to 4 (almost always). Items are summed, and total scores represent total levels of impulsivity. The total score thus ranges from 30 to 120, with a higher score indicating increased impulsivity. Factor analysis revealed three independent components in the BIS¹¹: attentional impulsiveness (assessing the ability to focus on the task at hand); motor impulsiveness (assessing the tendency to act on the spur of the moment); and non-planning impulsiveness (assessing the tendency to plan and think carefully). In the current research, attentional impulsiveness score (BIS_AI_Score), motor impulsiveness score (BIS_MI_Score), non-planning impulsiveness score (BIS_nPI_Score) and total score (BIS_Score) were used.

Short Scale for Creative Self (SSCS)

The SSCS ¹² was used to measure Creative Self-Efficacy (CSE) and Creative Personal Identity (CPI). The SSCS is composed of 11 items that are scored on a 5-point Likert scale – six which measure CSE and five of which measure CPI. The score of CSE (SSCS_CSE_Score) and CPI (SSCS_CPI_Score) were used in the current research.

Neuroticism-Extraversion-Openness Personality Inventory (NEO-PI-R)

The NEO-PI-R ¹³ includes 240 items that assess 30 specific traits to define five factors: neuroticism, extraversion, openness to experience, agreeableness, and conscientiousness. Items of the NEO-PI-R are rated on a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). In the current research, neuroticism score (NEO_N_Score), extraversion score (NEO_E_Score), openness to experience score (NEO_O_Score), agreeableness score (NEO_A_Score), and conscientiousness score (NEO_C_Score) were used.

Short-form Childhood Trauma Questionnaire (CTQ-SF)

The CTQ-SF ¹⁴ consists of 25 clinical items divided into 5 subscales (5 items each): emotional abuse, physical abuse, sexual abuse, emotional neglect and physical neglect to assess these five types of childhood trauma. Each of the 25 items is a 5-point Likert-style questions, rated from 1 (never) to 5 (very often) based on the frequency of each event.

Thus, total scores range from 25 to 125, while the scores of each subscale range from 5 to 25. In the current research, emotional abuse score (CTQ_SF_{Fea}_Score), physical abuse score (CTQ_SF_{Pa}_Score), sexual abuse score (CTQ_SF_{sa}_Score), emotional neglect score (CTQ_SF_{En}_Score), physical neglect score (CTQ_SF_{pn}_Score) and total score (CTQ_SF_Score) were used.

Connor-Davidson Resilience Scale (CD-RISC)

The CD-RISC¹⁵ consists of 25 items that measure individual's psychological resilience based on a 5-point Likert scale ranging from 0 to 4. In the current research, total score of CD-RISC (CD_RISC_Score) were used.

Curiosity and Exploration Inventory-II (CEI-II)

The CEI- II¹⁶ consists of 10 items that measure individual's trait curiosity based on a 5-point Likert scale ranging from 1 to 5. In the current work, total score of CEI-II (CEI-II_Score) was used.

Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ)

The SPSRQ¹⁷ is a 48 yes–no response item questionnaire which incorporates two scales: sensitivity to punishment (24 items) and sensitivity to reward (24 items). In the current research, score of sensitivity to punishment (SP_Score) and sensitivity to reward (SR_Score) were used.

Behavioral inhibition system and Behavioral activation system scales (BIS-BAS)

The BIS/BAS scales¹⁸ that measure individual's behavioral inhibition system (BIS) and behavioral activation system (BAS) consist of 24 items (20 score-items and 4 fillers) on a Likert scale ranging from 1 (very unlikely) to 4 (very likely). They include four subscales: the BIS scale (7 items), the BAS Reward (BASR-4 items), the BAS Drive (BASD-5 items), and the BAS Fun seeking (BASF-4 items). BIS is measured by the total score of BIS scale and BAS is measured by the total score of BAS Reward, BAS Drive and BAS Fun seeking. We used the score of BIS (BIS_BAS_I_Score) and score of BAS (BIS_BAS_A_Score) in the current research.

Schizotypal Personality Questionnaire–Brief (SPQ-B)

The SPQ-B^{19,20} is a 22 yes–no response item questionnaire which is used to assess individual schizotypy. This self-report measure contains three subscales: the cognitive-perceptual (positive) schizotypy dimension (8 items), the interpersonal (negative) schizotypy dimension (8 items) and the disorganized schizotypy dimension (6 items). In the current research, total score of SPQ-B (SPQ_B_Score) was used.

Pittsburgh Sleep Quality Index (PSQI)

The PSQI²¹ is a self-report questionnaire that consists of 19 items and 5 additional questions. The 19 items are combined to form 7 sleep quality component scores, including subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbance, sleep medication use, and daytime dysfunction. The total score of 7 components yield a global PSQI score ranging from 0 to 21. The last five questions are scored by another person (such as a bed partner or roommate); these items are typically

used for clinical information and are therefore not included in the scoring. In the current research, total score of PSQI (PSQI_Score) was used.

Adolescent Self-Rating Life Events Checklist (ASLEC)

The ASLEC²² is a self-assessment questionnaire consisting of 27 negative life events that may cause psychological reactions in adolescents. Participants were instructed to first determine whether the event occurred within a limited time or not (1 = did not occur; 2 = more than 12 months ago; 3 = within the past 12 months; 4 = currently ongoing) and rate the psychological impact of the life event (1 = no effect; 2 = mild; 3 = moderate; 4 = severe; 5 = extremely severe). The total score (ASLEC_Score) of 27 negative life events was used in our current research.

Emotion Regulation Questionnaire (ERQ)

The ERQ²³ consists of 10 self-report items that focuses on emotion-regulatory processes and strategies for emotion regulation and management based on a 7-point Likert scale (1 = strongly disagree and 7 = strongly agree). The questionnaire contains 10 items that capture two specific emotion regulation strategies, cognitive reappraisal and expressive suppression. The expressive suppression facet has four items and the cognitive reappraisal facet has six. In the current research, score of expressive suppression (ERQ_ES_Score) and cognitive reappraisal (ERQ_CR_Score) were used.

Need for Cognition (NFC)

The NFC²⁴ consists of 18 self-report items that is administered as an index of inherent cognitive motivation based on a 7-point Likert scale (1 = not at all and 7 = very much). In the current research, total score of NFC (NFC_Score) was used.

Social relationship scales (SRS)

The SRS²⁵ consists of 45 self-report items that is designed to summarize both the qualitative and quantitative aspects of a person's network of relationships based on a 5-point Likert scale (1 = never and 5 = always). The SRS can also be used as a social support indicator. The 45 items are combined to form 6 component scores, including emotional support (SRS_ES_Score), instrumental support (SRS_IS_Score), friendship (SRS_F_Score), loneliness (SRS_L_Score), perceived rejection (SRS_PR_Score) and perceived hostility (SRS_PH_Score). These six scores were used in the current research.

Satisfaction with life scale (SWLS)

The SWLS²⁶ consists of 5 self-report items that is designed to measure global cognitive judgments of satisfaction with one's life based on a 7-point Likert scale (1 = Strongly disagree and 7 = Strongly agree). The total score (SWLS_Score) was used in the current research.

Subjective well-being (SWB)

The SWB²⁷ consisted of 9 items, 8 of which belong to the index of general affects scale (e.g., 'how about the affective state you are experienced now?'), and the remaining one belongs to the life satisfactory questionnaire (e.g., 'how did you satisfied with your life?'). Each item is based on a 7-point Likert scale (1 = Very dissatisfied and 7 = Very satisfied). The total score (SWB_Score) was used in the current research.

Short grit scale (Grit-S)

The Grit-S²⁸ is a self-report questionnaire that consists of 8 items based on 5-point Likert scale (1 = not at all like me and 7 = very much like me). The scale includes two dimensions (each with four items): the consistency of interest, which reflects a person's maintenance of interest over an extended period of time; and the perseverance of effort, which reflects the tendency to keep trying in the face of failure or adversity. In the current research, score of consistency of interest (Grit_S_CI_Score) and perseverance of effort (Grit_S_PE_Score) were used.

Coping flexibility scale (CFS)

The CFS²⁹ is a 10-item assessment containing two subscales that measure evaluation coping and adaptive coping. Each subscale contains 5 items that are rated on a 4-point Likert scale (1 = very not applicable and 4 = very applicable). The score of evaluation coping (CFS_EC_Score) and score of adaptive coping (CFS_AC_Score) were used in the current research.

Perceived stress scale (PSS)

The PSS³⁰ consists of 14 self-report items that is used to measure the degree to which life in the past month has been experienced as unpredictable, uncontrollable and overwhelming on a 5-point response scale (1 = never and 5 = very often). The total score of PSS (PSS_Score) was used in the current research.

Behavioral and self-report measures (EV1 dataset)

Creative Achievement Questionnaire (CAQ)

The CAQ assesses 10 domains of creative achievements such as music and dance³¹. Each domain contains eight ranks with a score from 0 (I have no trained and recognized talent in this field) to 7 (my work is recognized nationwide), resulting in a skewed distribution, reflecting that few people have reached a high level of creative achievement^{31,32}. The total score of CAQ (CAQ_S_Score) was used in the current research. The scores of each domain were used in the current research: visual arts (CAQ_Va_Score), music (CAQ_Mu_Score), creative writing (CAQ_Cw_Score), dance (CAQ_Da_Score), drama (CAQ_Dr_Score), architecture (CAQ_Ar_Score), humor (CAQ_Hu_Score), scientific discovery (CAQ_Sd_Score), invention (CAQ_In_Score) and culinary (CAQ_Cu_Score). We used the total score in 7 areas including music as an assessment of artistic creativity (CAQ_art_Score) and used the total score in 3 areas including scientific discovery as an assessment of scientific creativity (CAQ_sci_Score)³³.

Inventory of Creative Activities and Achievements (ICAA)

The ICAA questionnaire³⁴ to assess the real-life creative activities and achievements across eight different creative domains (i.e., literature, music, art and crafts, creative cooking, sport, visual arts, performing arts, and science and engineering). The creative activities score (CAct_Score) reflects the frequency in which participants engaged in various creative activities. The creative achievements score (CAch_Score) estimated the level of achievement acquired in a creative domain. The CAct_Score and CAch_Score were used in the current research.

Williams' Creativity Assessment Packet (WCAT)

The WCAT ³⁵ contains 50 items (e.g. an item of imagination such as: 'If the final page of a storybook is missing, I will make up the story's ending myself'), provides scores for imagination, curiosity, challenge and risk-taking. Participants were asked to rate how much they agreed or disagreed with each item on a six-point Likert scale ranging from strongly disagree to strongly agree. The total score of WCAT (Williams_S_Score) and the scores of each dimension were used in the current research: imagination (Williams_I_Score), curiosity (Williams_Cur_Score), challenge (Williams_Cha_Score) and risk-taking (Williams_R_Score).

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