ORIGINAL ARTICLE

Is the richer, the happier? Moderating roles of personality-related brain connectivity

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ABSTRACT

Cultivated through the ages, the pursuit of psychological well-being (PWB) has long intrigued humanity, with prior research often examining its correlation with income. Nonetheless, predicting happiness based solely on income remains a challenge. Recent studies have highlighted personality traits as crucial moderators, exhibiting significant regulatory effects. This study seeks to explore how personality traits modulate the impact of individual income on PWB. Going beyond traditional personality trait scores, neural activity offers a multidimensional perspective on personality traits. Therefore, we utilize functional connectivity as variables reflecting personality traits in moderation analyses. Leveraging large-scale resting-state functional magnetic resonance imaging data, our findings underscore the pivotal moderating role of personality trait-related functional connectivity. Specifically, connections associated with the cerebellum, particularly those involving the cerebellum's neural activity, play a crucial role. This research enriches our comprehension of the relationship between income and well-being and delves into the neural mechanisms underlying the moderating influence of personality traits.

Key words: psychological well-being, personality, income, functional connectivity, human connectome project, moderating analysis

INTRODUCTION

What constitutes the source of psychological well-being (PWB) and happiness According to the "Living well" theory (Salsman *et al.*, 2014), PWB can be categorized into two broad components: affective experiences and cognitive evaluations. These components encompass three key dimensions:(1) positive affect (affective experiences), (2) life satisfaction, and (3) meaning and purpose (cognitive evaluations). The concepts of PWB and happiness significantly overlap. Ruut Veenhoven posits that happiness is a positive emotional experience derived from a meaningful life and subjective life satisfaction (Veenhoven, 2012). It involves personal positive emotions and life satisfaction but focuses primarily on hedonic aspects without emphasizing life's meaning and goals. In contrast, PWB not only includes aspects of happiness but also places significant importance on meaning and purpose.

While a commonly held belief asserts that "Money can't buy happiness", paradoxically, divergent views prevail in social discourse (Clark, 2017). Some contend that "Money is akin to a smoothing iron capable of alleviating life's tribulations (Sacks *et al.*, 2010)". In academic circles, the discourse surrounding the relationship between PWB and money remains pervasive and contentiou (Diener *et al.*, 2013; Sacks *et al.*, 2012; Sengupta *et al.*, 2012).

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Income is the primary source through which people acquire money. According to Mankiw's "Principles of Economics", Individuals and households receive income through many sources like labor and investment, and this income is usually held in the form of money, which can be in cash or bank accounts (Mankiw, 2021). For instance, previous studies have explored the correlation between income and PWB. In previous research, income has been found to predict all PWB dimensions, both cross-sectionally and longitudinally (Kaplan *et al.*, 2008). PWB has been found to have a significant but weak positive correlation with income (correlation coefficients generally ranging from 0.10 to 0.20) (Mullis, 1992; Sugiura & Sugiura, 2018; Yasmeen & Ejaz, 2021). In a study on lower-middle-class families in Turkey, income was significantly and moderately positively correlated with all dimensions of PWB (correlation coefficients ranging from 0.303 to 0.605) (Yasmeen & Ejaz, 2021). Some Studies have also explored the correlation between income and happiness. A comprehensive study spanning 24 years across 19 countries and three continents revealed a distinct positive correlation between income and happiness within nations (Easterlin, 1974). Other studies also supported this positive correlation between income and happiness. That is, income can positively predict happiness (La *et al.*, 2021; Yang *et al.*, 2022; Ye *et al.*, 2023). A twin study conducted in China involving 750 pairs of identical twins and 456 pairs of fraternal twins demonstrated a significant positive correlation between income and happiness. Doubling income resulted in a 0.26-unit increase in happiness scores, equivalent to a 0.37 standard deviation increase (Ye *et al.*, 2023). The above evidence indicates a possible positive correlation between PWB and income, laying the groundwork for the formulation of our hypothesis.

Nevertheless, income is one facet within the multifaceted framework contributing to subjective well-being (López Ulloa *et al.*, 2013) (includes overall life satisfaction, experiencing positive emotions, and a reduction in negative emotions [Sugiura & Sugiura, 2018]), happiness (Uchida & Ogihara, 2012), life satisfaction (Chen *et al.*, 2020; Khodabakhsh, 2022), and PWB (Campbell *et al.*, 1976). A paradox emerges in the relationship between PWB and income. A large-scale study on quality of life indicates that some high-income families report low levels of PWB. In contrast, some low-income families report high levels of PWB (Campbell *et al.*, 1976). Income augmentation also does not consistently portend a concomitant rise in subjective well-being. Renowned scholar Easterlin posited the "Easterlin paradox" grounded in his research discoveries: Despite the exponential growth observed in per capita income over time, the parallel trajectory of happiness exhibits relative stability (Easterlin, 1995). This phenomenon may stem from the intricate nature of real-life experiences, where happiness is influenced not solely by one factor but by the complicated interplay among multiple factors, as mentioned earlier (Fan *et al.*, 2021a; Luo *et al.*, 2022). The above study results demonstrate the potentially complex relationship between PWB and income and possible moderating variables, which warrant further investigation.

Previous studies have indicated that personality traits can modulate the relationship between income and happiness (Chang & Ma, 2011; Proto & Rustichini, 2015; Soto, 2013; Syrén *et al.*, 2020). Empirical investigations conducted by scholars Proto and Rustichini have revealed the nuanced moderating role of neuroticism in shaping the relationship between income and life satisfaction. The correlation between income and life satisfaction exhibits heightened strength among individuals with lower income and higher neuroticism. In contrast, it diminishes among those with higher income and elevated neurotic tendencies. For those with high income, individuals with higher levels of neuroticism derive less satisfaction from additional income compared to those with lower levels of neuroticism. Conversely, for those with low income, individuals with higher levels of neuroticism derive more satisfaction from additional income than those with lower levels of neuroticism. When considering the interaction between income and neuroticism, income alone does not significantly impact (Proto & Rustichini, 2015).

Syrén's team has also elucidated the role of personality traits as moderators in the intricate nexus between income and mental well-being (Syrén *et al.*, 2020). Specifically, extraversion, agreeableness, and neuroticism exhibit adverse moderation effects on the relationship between monthly income and mental well-being, while openness demonstrates a positive moderation effect. Individuals with higher neuroticism scores tend to experience heightened life satisfaction with increased income. Since income is the primary source through which people acquire money, the investigation of the attitude towards money and personality can show the relationship between income and personality. In a complementary study, Chang and Ma delineated the intricate interplay of personality traits as partial mediators in the predictive linkages between overall happiness and attitudes toward money (Chang & Ma, 2011). Neuroticism emerges as a significant positive predictor of dimensions such as distrust and money anxiety within money attitudes, whereas extraversion emerges as a negative predictor of the dimension of distrust. Concurrently, the maintenance-reservation dimension within money attitudes positively correlates with happiness, while the dimension of distrust exhibits a negative association with happiness (Chang & Ma, 2011).

Having established the intricate interplay between personality traits and their moderating or mediating effects on the relationship between income and well-being, it is crucial to delve into the neurobiological underpinnings accompanying these observed phenomena (Kong *et al.*, 2015; Urry *et al.*, 2004). According to previous studies, it is evident that there are many shared neural pathways between personality traits and well-being, such as the insula, precuneus, amygdala, thalamus, and posterior cingulate cortex (PCC) (Kruschwitz *et al.*, 2015; Li, 2018; Li *et al.*, 2020; Luo *et al.*, 2016; Passamonti *et al.*, 2015; Ryan *et al.*, 2011; Sato *et al.*, 2019; Wei *et al.*, 2011). Through mediation analysis, it was found that the average functional connectivity and global network efficiency can mediate the effect of personality traits on PWB (Kong *et al.*, 2015), and thalamic and insular connectivity significantly mediated the association between neuroticism and eudaimonic well-being (Li *et al.*, 2023). These findings underscore the complexity of how personality traits influence PWB, indicating that this relationship cannot be adequately captured solely by simple personality trait scores. Moreover, personality assessment through self-report questionnaires is susceptible to biases such as social desirability, impression management, and self-deception (Hildebrand *et al.*, 2018). Even with consistent core items, variations in questionnaire wording and format can impact the stability of personality measurements (Watson, 2004). Therefore, using more objective measures, such as neuroimaging methods, not only provides explanatory rather than descriptive theories for personality traits (DeYoung *et al.*, 2010) but also avoids the effects of social desirability, impression management, and self-deception.

Previous studies have found that the relationship between personality traits and PWB is influenced by numerous complex cognitive functions (Kunisato *et al.*, 2011; Salsman *et al.*, 2014; Waris *et al.*, 2018). For instance, neuroticism may impact well-being through self-consciousness, emotional awareness, cognitive control, performance monitoring, and autobiographical memory (Kong *et al.*, 2015; Li *et al.*, 2023). These mental activities require effective information exchange between different brain regions, and the interactions among these cognitive processes are crucial for understanding the relationship between personality traits and PWB. Functional connectivity reflects the level of communication between brain regions, indicating the information exchange and interaction among different brain areas (Luo *et al.*, 2022; van den Heuvel & Hulshoff Pol, 2010). Therefore, employing functional connectivity to represent personality traits is likely to provide deeper insights into the intricate relationship between personality and PWB.

Therefore, the primary objective of this study is to analyze functional magnetic resonance imaging (fMRI) data corresponding to personality traits to systematically explore the potential moderating effects of personality variables on the intricate relationship between income and well-being. As highlighted earlier, the rationale for selecting neurophysiological characterization data in this research is grounded in its capacity to comprehensively elucidate the biological foundations of personality traits.

Based on the evidence above, we posit the following hypotheses: (1) Neuroticism and income interact: Among individuals with stronger functional connections associated with neuroticism, the positive predictive effect of income on PWB is heightened (Hussain, 2017; Speed *et al.*, 2018). (2) Extraversion and income interact: Within groups exhibiting enhanced functional connections linked to extraversion, the adverse impact of income reduction on PWB is diminished compared to groups characterized by weaker functional connections associated with extraversion (Hussain, 2017; Speed *et al.*, 2018).

This investigation is poised to establish a foundation for delving into the potential neurobiological underpinnings of personality, thereby providing crucial cognitive neuroscientific support for forthcoming research on personality traits. Consequently, this study holds considerable scientific reference value and is positioned to make a meaningful contribution to future research endeavors within this domain (Easterlin, 1974). Furthermore, using fMRI data as quantitative metrics for personality variables offers a distinct advantage in minimizing errors compared to self-reported data, thereby mitigating potential biases arising from social desirability and rater biases (Edwards, 1957). Additionally, we used household income in our analysis because it offers several advantages over personal income. Fluctuations in income among family members can balance each other out, providing a more stable measure of economic status. Many economic and social phenomena, such as consumption behavior, savings, and educational expenses, are related to household units. Therefore, using household income allows for more accurate analysis and prediction of these phenomena (Mankiw, 2021). Moreover, household income helps maintain consistency and comparability across statistical data, providing a standardized way to measure the economic status of households. This enhances the reliability and comparability of various financial data and analyses (Juhn & Murphy, 1997). Consequently, we chose household income for our analysis.

METHOD

Overview

In our analytical approach, we initially utilized each connectivity strength as a moderator variable in

predicting happiness based on income. We identified edges that demonstrated significant moderating effects and established significant correlations with personality traits. Subsequently, weights were assigned to edges corresponding to each personality trait, and a composite score was computed. This composite score was then employed as a moderator variable in predicting PWB based on income.

Database

All data, including income, PWB, personality traits, and neuro-imaging data, were accessed from the Human Connectome Project (HCP) 1200 Subjects Data Release (Van Essen *et al.*, 2012). We employed pre-existing high-level resting-state functional Magnetic Resonance Imaging (rs-fMRI) connectivity analyses, which included precomputed functional connectivity matrices by the HCP. The details of the imaging data analysis will be explained below. We chose household income as the representation of monetary resources. Income levels were quantified using the Semi-Structured Assessment for the Genetics of Alcoholism (SSAGA) and encoded into eight categories: < $10,000 = 1; 10,000-19,999 = 2; 20,000-29,999 = 3; 30,000-39,999 = 4; 40,000-49,999 = 5; 50,000-74,999 = 6; 75,000-99,999 = 7; ⩾ 100,000 = 8. Personality traits were assessed using the five-factor model and measured by the Neuroticism Extraversion Openness Five-Factor Inventory (NEO-FFI), which has demonstrated excellent reliability and validity (McCrae & Costa, 2004). The scale includes "general life satisfaction", "meaning and purpose", and "positive affect". General life satisfaction primarily measures satisfaction with various aspects of life (*e.g.*, "I am satisfied with my life"), meaning and purpose encompass several related yet distinct elements, such as coherence in life, perceiving life as valuable and meaningful, engaging in personally fulfilling activities, and having a sense of purpose. Positive affect is divided into three factors: the first factor reflects high activation emotions (*e.g.*, "I felt joyful"), the second factor includes low activation emotions (*e.g.*, "I felt peaceful"), and the third factor involves cognitive engagement (*e.g.*, "I felt attentive") (Salsman *et al.*, 2014). Participants self-reported their PWB through the National Institutes of Health (NIH) Toolbox PWB surveys (http://www.nihtoolbox.org). Previous research has shown correlations between overall life satisfaction, meaning and purpose, and positive effect on income (Diener & Biswas-Diener, 2002; Kahneman & Deaton, 2010; Kasser & Ryan, 1996). Therefore, The PWB score in our study was calculated as the sum of the scores from these three dimensions. It is important to note that all data used in this study were obtained in compliance with the HCP guidelines and ethical standards.

All studies were approved by the ethics committee of Department of Psychology, Sun Yat-sen University. Written informed consent was provided by each participant before they took part in the HCP and this project was approved by the Institutional Review Board for ethical research.

Imaging data processing

The dataset consisted of data from all 1003 subjects, each with four complete rs-fMRI runs. The preprocessing pipeline utilized was the minimally-preprocessing pipeline (Glasser et al., 2013), coupled with artifact removal using Independent Component Analysis followed by the FMRIB's Expert Analysis Tool (ICA+FIX) (Griffanti *et al.*, 2014; Salimi-Khorshidi *et al.*, 2014). Following preprocessing, the data underwent group Principal Component Analysis (PCA) and were fed into group Independent Component Analysis (ICA).

During this process, spatial ICA maps were overlaid onto each subject's rs-fMRI time series data to extract a representative time series for each ICA component. Treating each ICA component as a network "node", a partial temporal correlation was computed between the nodes' time series. The correlation values were subsequently transformed from Pearson correlation scores (R-values) to Z-statistics. These steps collectively yielded the average functional connectivity matrix for each subject. We choose 300 distinct ICA components as our materials. Interested readers can refer to the official HCP website for more detailed information.

Functional connectivity matrix analysis

We excluded nine subjects with incomplete data from the analysis. Subsequently, we employed each edge as a moderator variable representing the correlation between two nodes. Income was considered the independent variable in the prediction of PWB. Our objective was to identify edges with significant moderating effects, and false discovery rate (FDR) correction was applied to adjust *P*-values, with a threshold set at $P = 0.01$. However, no edge survived the correction. The entire moderator analysis was conducted using a linear model.

In light of the absence of edges meeting the correction criteria, the data using uncorrected P-values that were below the threshold. After identifying significant moderating edges, Pearson correlations were computed between these edges and the five personality traits. To ensure the robustness of our findings, *P*-values underwent correction for multiple comparisons using FDR, with a threshold set at $P = 0.01$. Unfortunately, no edge met the criteria for significance after correction. Next, we used the functional connection of $P < 0.01$ to represent the personality trait for subsequent analyses and calculations (not corrected by FDR).

Statistical analysis

Our statistical approach comprises two steps. First, for each personality trait, PCA was employed to ascertain the weights of each edge representing the personality trait. Then, based on the weights, we obtain the functional connectivity scores for each personality trait of each subject. Specifically, the functional connectivity scores were calculated by the weighted average of each edge. Utilizing these functional connectivity scores, we predicted the personality trait scores of the subjects and obtained significant results. In the second step, the model presented in Equation (1) was employed to test our hypotheses. This model incorporates the main and interaction effects between household income and the neural functional network of the five personality traits: $Y_i = \alpha_0 + \alpha_1 M_i + \beta_0 X_i + \beta_1 M_i \times X_i + \varepsilon$, (1).

Where Y represents the PWB score of participants, X denotes household income, M is the moderator variable, and M × X represents the interaction term between the moderator and income. The moderating variables utilized were participants' neural functional connectivity scores for each personality trait: Neuroticism, Extroversion, Openness, Conscientiousness, and Agreeableness. We examined whether the effect of household income on the PWB of subjects is moderated by these personality traits using linear regression. All independent variables were standardized to mitigate multicollinearity. A logarithmic transformation was applied to the PWB score. The goodness-of-fit was assessed using R^2. All estimations were conducted using SPSS 27.0.

RESULTS

Functional connectivity matrix analysis

After the analysis, we identified 2563 edges exhibiting significant moderating effects. Within this subset, we observed significant correlations with personality traits: 4 edges were significantly correlated with agreeableness (including three positively correlated edges and one negatively correlated edge), three edges with conscientiousness (one positive and two negative), five edges with extroversion (two positive and three negative), ten edges with neuroticism (three positive and seven negative), and three edges with openness (two positive and one negative), Detailed information is available in Figure 1 and Table S1-S5. Screening out the most relevant edges of personality traits among the vast number of functional connections will help us construct a representative neural functional network of personality traits. The weighted average of these edges was performed to obtain the functional connectivity scores of the corresponding personality traits (Table S6-S10), and these functional connectivity scores will be used as our moderating variables for regression analysis in the following studies (See the Methods section for details).

Statistical analysis result

Table 1 summarizes descriptive statistics of moderator variables used in the study. We observed significant interaction effects between income and the neural function network of Neuroticism ($\beta = 0.013$, $t = 6.403$, $P < 0.001$). In addition to the regression results, we present the interaction effects in Figure 2 and Table 2 to facilitate the interpretation of moderation. Simple slope analyses indicated a positive correlation between income and PWB for individuals with a relatively high level of neuroticism (whose functional connectivity score was one standard deviation [SD] above the mean), $\beta = 0.029$, $P < 0.001$ (Table S11). In contrast, there was no significant relationship between income and PWB for individuals with a relatively low level of neuroticism (1 SD below the mean), $\beta = 0.000$, $P = 0.867$. The plotted lines illustrate the support for Hypothesis 1, suggesting that the PWB of individuals with high levels of neuroticism is more susceptible to the influence of income.

The interaction effect between income and the neural function network of Extroversion was significant $\beta = -0.016$, $t = -3.890$, $P < 0.001$), Simple slope analyses indicated that income was positively correlated with PWB for individuals with relatively low levels of extroversion, $\beta = 0.036$, $P < 0.001$. In contrast, there was no relationship between income and PWB for individuals with relatively high levels of extroversion, $\beta = -0.007$, $P = 0.150$. Plot lines illustrate the support for Hypothesis 2, stating that the PWB of individuals with low levels of extroversion is more likely to be affected by income (Figure 3).

We also observed a significant interaction effect between income and the neural function network of Openness (Figure 4) and an interaction effect between income and the neural function network of Conscientiousness (Figure 5). These results suggest that individuals with high levels of openness and conscientiousness are less likely to have their PWB affected by income. The interaction effect between income and the neural function network of Agreeableness is insignificant, illustrating no moderation effect of Agreeableness.

DISCUSSION

This study aims to investigate the impact of income on PWB and the moderating effect of personality traits, which are indexed by brain connectivity. The results reveal that individuals with heightened levels of neuroticism demonstrate a heightened susceptibility of their PWB to income fluctuations. Specifically, under conditions of low household income, individuals charac-

Table 1: Descriptive statistics of participants (*N* = 994)

Variable	Description	M	SD	Min	Max
PWB score	The sum of life satisfaction score, meaning and purpose score and positive affect score	157.09	21.67	81.40	217.80
Household income	Total household income*	5.09	2.14	1.00	8.00
Age	Age in years	28.74	3.70	22	37
Gender	0-female, 1-male	0.47	0.50	0	1
NEOFAC_N	NEO- FFI Personality Neuroticism	16.40	7.33	0	43
NEOFAC_O	NEO- FFI Personality Openness	28.46	6.22	10	47
NEOFAC_E	NEO- FFI Personality Extroversion	30.72	5.99	10	47
NEOFAC_C	NEO- FFI Personality Conscientiousness	34.46	5.94	11	48
NEOFAC_A	NEO- FFI Personality Agreeableness	33.58	5.79	10	48

* < $10,000 = 1, 10k-19,999 = 2, 20k-29,999 = 3, 30k-39,999 = 4, 40k-49,999 = 5, 50k-74,999 = 6, 75k-99,999 = 7, >= 100,000 =8. M, mean score of variables; SD, standard deviation of variables; Min, minimum values; Max, maximumindicate values; NEOFAC, Neuroticism Extraversion Openness Five-Factor Inventory_Neuroticism; NEOFAC_O, Neuroticism Extraversion Openness Five-Factor Inventory_Openness; NEOFAC_E, Neuroticism Extraversion Openness Five-Factor Inventory_Extroversion; NEOFAC_C, Neuroticism Extraversion Openness Five-Factor Inventory_Conscientiousness; NEOFAC_A, Neuroticism Extraversion Openness Five-Factor Inventory_Agreeableness.

Table 2: Regression analysis result (*N* = 994)

Model	Variable	Coefficient	*SE*	*t*	*P*
1	(Constant)	5.047	0.004	1170.007	<0.001
	Income	0.015	0.002	7.206	<0.001
	FC- N	-0.019	0.004	-4.343	<0.001
	FC- E	0.022	0.009	2.483	0.013
	FC- O	0.009	0.004	1.973	0.049
	FC- C	0.008	0.004	1.768	0.077
	FC- A	0.001	0.004	0.255	0.799
2	(Constant)	5.046	0.004	1219.379	<0.001
	Income	0.015	0.002	7.907	<0.001
	FC- N	-0.014	0.004	-3.265	0.001
	FC- E	0.019	0.008	2.206	0.028
	FC- O	0.006	0.004	1.378	0.169
	FC- C	0.006	0.004	1.525	0.128
	FC- A	0.002	0.004	0.385	0.700
	FC- N* Income	0.013	0.002	6.403	<0.001
	FC- E* Income	-0.016	0.004	-3.890	<0.001
	FC- O* Income	-0.007	0.002	-3.559	<0.001
	FC- C* Income	-0.005	0.002	-2.411	0.016
	FC- A* Income	-0.003	0.002	-1.579	0.115

We employed two models to predict PWB scores. In Model 1, only the level of income and functional connectivity (FC), which is related to personality scores, were used as independent variables (IV). FC-N, functional connectivity of Neuroticism; FC-E, FC of Extraversion; FC-O, FC of Openness; FC-C, FC of Conscientiousness; FC-A, FC of Agreeableness. In Model 2, we included the interaction between FC and income as an additional IV. SE, standard error.

terized by high neuroticism report diminished PWB compared to those with low neuroticism. Additionally, our findings suggest that individuals with lower levels of extroversion are more susceptible to the impact of income on their PWB. Conversely, individuals characterized by heightened levels of openness and conscientiousness exhibit greater resilience, as their PWB appears less influenced by income fluctuations. Previous literature has established that individual personality traits influence emotional regulation strategies and cognitive processes, thereby impacting PWB (Morawetz *et al.*, 2020). Specifically, household income is inversely correlated with negative emotions (Clingingsmith, 2016; Yu & Chen, 2016). When individuals experience negative emotions triggered by poverty, their emotional regulation and cognitive coping strategies—modulated by personality traits—can have varying effects on well-being (Zhu *et al.*, 2023). Research indicates that

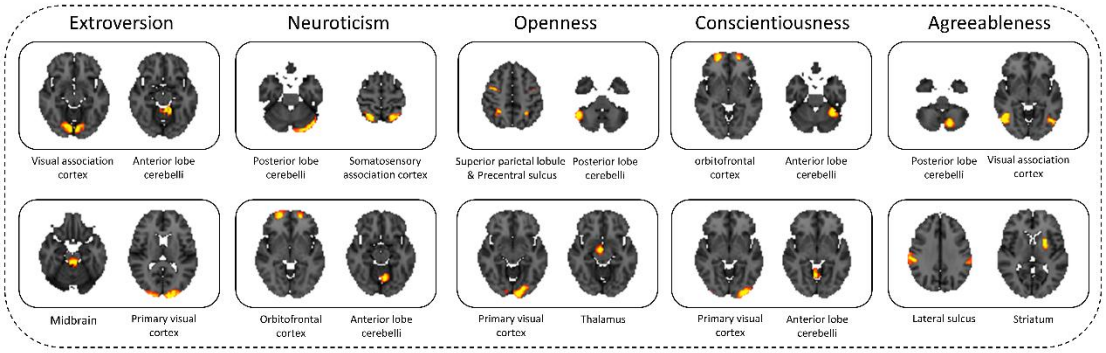

Figure 1. Edges with significant moderating effects related to personality traits. The functional connectivity results indicate that highlighted regions exhibit similar activation patterns. For each personality trait, we displayed two edges with the largest absolute weights in the figure, while additional edges can be found in the supplementary materials. The brain cross-section images are sourced from the official HCP dataset.

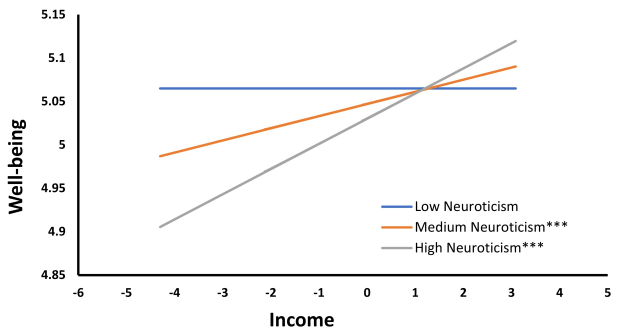

Figure 2. Interaction effects plot (Income × Neuroticism). The vertical axis represents the PWB score of participants, calculated as the logarithm of the sum of life satisfaction, meaning and purpose, and positive affect scores. The horizontal axis depicts the household income of participants, categorized as follows: <$10,000 = 1, 10k-19,999 = 2, 20k-29,999 = 3, 30k-39,999 = 4, 40k-49,999 = 5, 50k-74,999 = 6, 75k-99,999 = 7, ≥ 100,000 = 8. The asterisks (***) indicate that the positive relationship between income and PWB was significant only for participants with medium or high neuroticism levels ($P < 0.01$).

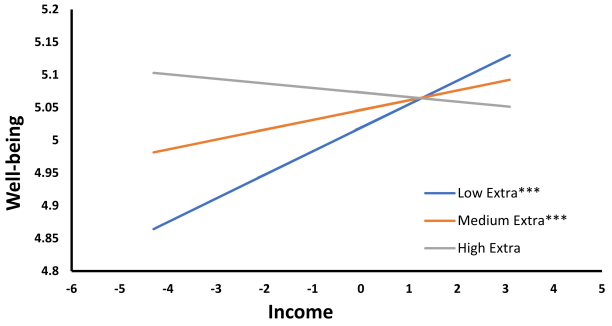

Figure 3. Interaction effects plot (Income × Extroversion). Simple slopes analyses indicate a positive correlation between income and PWB for individuals with relatively low levels of extroversion. The asterisks (***) indicate that the positive relationship between income and PWB was significant only for participants with medium or low extroversion levels ($P < 0.01$).

individuals with high levels of neuroticism tend to be more prone to worry, depression, emotional instability, self-indulgence, jealousy, and dissatisfaction (John & Srivastava, 1999), and they may also encounter greater financial difficulties (Nyhus & Webley, 2001). In contrast, individuals with high levels of extraversion, openness, and conscientiousness typically employ positive coping strategies when facing challenges. Those high in extraversion and openness are more inclined to seek external support and cultivate harmonious interpersonal relationships, which reduces their susceptibility to anxiety (Connor-Smith & Flachsbart, 2007). It can be inferred that individuals with high levels of neuroticism are more likely to experience negative emotions and distress due to low income and a tendency toward debt. Conversely, individuals with high levels of extraversion, openness, and conscientiousness are more likely to seek constructive solutions and maintain positive interpersonal relationships, even in the face of low income. This proactive approach allows them to gain social support and positive emotions from others, thereby mitigating the adverse effects of low income. Therefore, it is evident that individuals with different personality traits experience varying levels of PWB when confronted with low income, which further supported our results.

Our study unveils distinct neural connections that modulate the relationship between income, PWB, and their correlation with personality traits. Specifically, connections linking the superior parietal lobule to the posterior cerebellum and the orbitofrontal cortex to the anterior cerebellum emerge as pivotal in moderating the impact of neuroticism on income and PWB. Furthermore, connectivity between the central lobule and the occipital lobe and connections between the

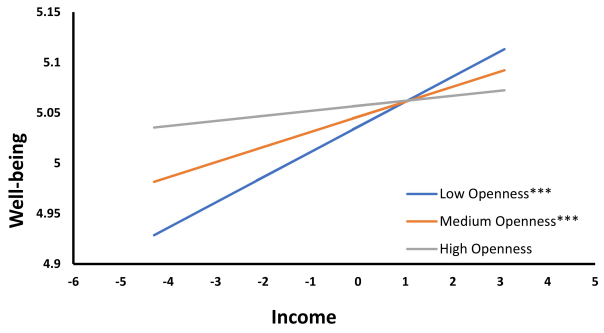

Figure 4. Interaction effects plot (Income × Openness). Simple slopes analyses indicate a positive correlation between income and PWB for individuals with relatively low levels of openness. The asterisks (***) indicate that the positive relationship between income and PWB was significant only for participants with medium or low openness levels ($P < 0.01$).

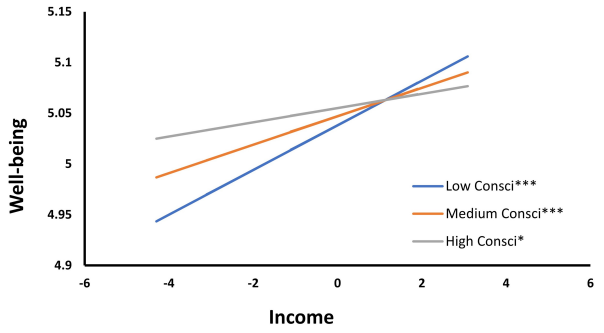

Figure 5. Interaction effects plot (Income × Conscientiousness). The asterisks (*** /*) indicate that the positive relationship between income and PWB significant for participants with low, medium or high conscientiousness levels ($P < 0.01$/ $P < 0.05$).

midbrain and the occipital lobe is deemed significant when extroversion moderates. Additionally, our findings underscore the importance of connections between the thalamus and the occipital lobe, as well as between the dorsal prefrontal lobe and the cerebellum, in modulating the influence of openness. Moreover, the connectivity linking the orbitofrontal cortex to the left posterior lobe of the cerebellum emerges as a pivotal regulator associated with conscientiousness.

In our investigation, many connections linked to the cerebellum have been discerned. Previous scholarly endeavors have firmly established the cerebellum's involvement in sensorimotor functions and pivotal roles concerning emotional regulation and cognitive processing (Dai *et al.*, 2022). Diverse activation patterns within the cerebellum have been observed across various tasks, encompassing working memory, attention, language, executive functions, and emotional processing (Brissenden & Somers, 2019). This diversity is postulated to stem from the intricate existence of cognitive functional loops between the cerebellum and the brain, facilitating extensive bidirectional communication (Kunisato *et al.*, 2011).

However, agreeableness is the only personality trait we found that does not have a significant moderating effect. This can be attributed to two primary reasons: Firstly, the null effect of agreeableness in our results may be linked to the independent variable we used in our analysis, namely, family household income. It's crucial to note that individuals with varying levels of agreeableness within the same household share the identical household income value. This disparity in agreeableness levels amidst identical household income contexts could result in a diminished impact of household income on PWB for highly agreeable individuals, thus statistically explaining the observed null effect of agreeableness in our findings. Moreover, previous research has shown that individuals with high agreeableness are more likely to face financial difficulties (Schmutte & Ryff, 1997) because they tend to accommodate others (Watson, 2014) and are therefore more willing to sacrifice their personal resources for others (Quan *et al.*, 2019). When facing stressful events, they actively seek external emotional support, thereby reducing anxiety (Lyon *et al.*, 2021). Therefore, we hypothesize that household income does not significantly affect the PWB of individuals with high agreeableness. Research has found that individuals with high agreeableness are more prone to experiencing financial difficulties (Matz & Gladstone, 2020) because they are more likely to accommodate others (de Dreu & van Lange, 1995) and thus more willing to sacrifice their personal resources for others (Judge *et al.*, 2012). From this, we can infer that individuals with low agreeableness are less likely to make concessions to others and, therefore, less likely to face financial difficulties. Therefore, highly agreeable individuals are more likely to make concessions to other family members, reducing their own benefits. At the same time, those with low agreeableness can better secure more benefits for themselves. This may relatively reduce the disparity in the impact of household income on the PWB of individuals with different levels of agreeableness. In conclusion, the moderating effect of agreeableness on household income and PWB may also be affected by other factors, such as family relationships, which can be further explored.

In addition, individuals with high agreeableness are characterized by trust in others, generosity, humility, and empathy (Heaven *et al.*, 2013). Previous studies have shown that individuals with high agreeableness generally have higher levels of PWB (Schmutte & Ryff, 1997).

Compared to other personality traits, agreeable individuals place less importance on money (Watson, 2014) and tend to remember and recall positive information (Quan *et al.*, 2019). When facing stressful events, such as limited access to money, they actively seek external emotional support, thereby reducing anxiety and maintaining the current level of happiness (Ka & Lje, 2021). Therefore, this poverty resilience of highly agreeable individuals may contribute to the null effect of agreeableness observed in our analysis. In conclusion, the moderating effect of agreeableness on household income and PWB may also be influenced by other factors, such as family relationships, which warrant further exploration.

The practical ramifications of this study extend to the exploration of PWB and the measurement of personality traits through resting-state fMRI. Many individuals grapple with distress from their modest income, significantly impacting their overall PWB (Clark et al., 2013; Gill, 2014). Moreover, individuals sharing comparable income levels may manifest disparate levels of PWB, a phenomenon potentially influenced by distinct personality traits (Boyce & Wood, 2011; Schurer & Yong, 2012; Syrén *et al.*, 2020). Our findings clarify the moderating influence of personality traits on the nexus between income and PWB. An avenue for augmenting PWB may be fostering an optimistic and open demeanor. Consequently, individuals are encouraged to contemplate personal transformation as a mechanism for enhancing PWB, transcending a sole reliance on external factors for PWB improvement.

This study discerns functional brain connections corresponding to specific personality traits and elucidates the functional networks associated with each trait, thereby introducing a novel metric for gauging personality attributes. Conventional personality assessment tools, notably questionnaires, are marred by individual subjectivity, social desirability bias, and intentional deception. Consequently, this innovative measurement approach holds the potential to mitigate errors and find versatile applications, including the evaluation of personality traits in forensic contexts.

LIMITATION

Although previous studies have found that functional connectivity can predict personality traits (Brooks *et al.*, 2020; Nostro *et al.*, 2018; Tran *et al.*, 2006), it is undeniable that personality traits are complex constructs influenced by a multitude of factors, including genetics (Hopwood *et al.*, 2011), the natural environment (Hopwood *et al.*, 2011), and the social environment (Peng & Luo, 2021) . While functional connectivity offers valuable insights into the neural basis of personality traits, it alone cannot fully capture their intricacies. Future research should aim to integrate genetic, neural, environmental, and social factors to provide a more comprehensive understanding of personality traits. Recent studies have introduced representation similarity analysis as a novel tool to extract the degree of association between different dimensions, thereby constructing global feature patterns of object variables (Fan *et al.*, 2021b; Luo et al., 2017; Luo *et al.*, 2024; Yuan & Luo, 2024). Incorporating such perspectives and methodologies in future research could provide a more nuanced understanding of the complex, multi-factorial nature of personality traits.

Furthermore, our fMRI data has not undergone correction for multiple comparisons, thereby introducing the possibility of type one errors. In future research endeavors, we aspire to employ more rigorous statistical methodologies and substantiate the generalizability of our results across diverse databases.

CONCLUSION

Our empirical findings provide compelling evidence that core personality traits, including neuroticism, extraversion, openness, and conscientiousness, wield a discernible moderating influence on the intricate interplay between household income and overall PWB.

DECLARATION

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Author contributions

Shu FQ: Conceptualization, Resources, Data curatio, Methodology, Validation, Writing—Original draft, Writing—Review and Editing; Xiong JB: Conceptualization, Resources, Data curatio, Methodology, Validation, Writing—Original draft, Writing—Review and Editing; Lin J: Conceptualization, Resources, Data curatio, Methodology, Validation, Writing—Original draft, Writing—Review and Editing; Zhang Y: Conceptualization, Methodology, Writing—Original draft, Writing—Review and Editing; Luo SY:Conceptualization, Project administration, Writing—Original draft, Writing—Review and Editing. All authors commented on the manuscript.

Ethics approval

All studies were approved by the ethics committee of Department of Psychology, Sun Yat-sen University. Written informed consent was provided by each participant before they took part in the HCP and this

project was approved by the Institutional Review Board for ethical research.

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Conflict of interest
Luo SY is the editorial board member of the journal. The article was subject to the journal's standard procedures, with peer review handled independently of the editor and the affiliated research groups.

Use of large language models, AI and machine learning tools
None declared.

Data availability statement
No additional data.

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