Low neuroticism and cognitive performance are differently associated to overweight and obesity: A cross-sectional and longitudinal UK Biobank study

Gaia Olivo*, Shaili Gour, Helgi B. Schiöth

Department of Neuroscience, Functional Pharmacology, Uppsala University, Uppsala, Sweden

ABSTRACT

Background: A growing body of research has linked personality traits to cognitive performance. This relationship might play a role in the predisposition toward obesity. Neuroticism and executive function seem to be particularly involved, and reduced executive function has been proposed to underlie the association of neuroticism with sedentary behaviors and fatty food consumption. Despite the link between neuroticism, cognitive functions and obesity has been largely reported, conflicting evidence exists. Moreover, information regarding other cognitive domains, and studies on overweight individuals, are still scarce.
Methods: We examined cross-sectional associations of neuroticism and cognitive function with overweight and obesity in a sample of 170 310 individuals from the UK Biobank cohort, adjusted for sociodemographic and lifestyle factors. Measures on fluid intelligence (FI) (reasoning ability), trail making test (TMT) (executive function), numeric memory test and pairs matching (PM) task (short-term memory) were extracted from the database. Correlations between neuroticism and cognitive performance were explored. Moreover, we investigated whether neuroticism and executive function could predict BMI variability over time.
Results: Reduced FI and short-term memory were associated with overweight and obesity, while reduced executive function was associated with obesity but not with overweight. Low neuroticism was associated with being overweight rather than lean or obese independently of gender and life-style. Furthermore, baseline neuroticism scores could predict BMI variations over 5–10 years follow-up, and high neuroticism correlated with lower cognitive performance.
Conclusions: Lower cognitive performance is associated with both overweight and obesity, except for executive function, which was only related to obesity. Neuroticism correlated with performance on most of the cognitive domains tested, supporting the link between personality and cognition. Our findings also support the role of neuroticism in leading to greater weight variability over time, rather than to overweight/obesity itself.

1. Introduction

Personality traits can be used to identify the appropriate weight loss treatment and management strategies for obese patients (Munro et al., 2011). The outcome of different weight loss interventions in obese people seems to be influenced by their underlying personality traits (Gerlach et al., 2015). For example, obese people with high reward dependence and cooperativeness are more willing to participate in behavioral group therapies (Sullivan et al., 2007). Moreover, patients with lower novelty seeking are more likely to effectively lose gain with this type of intervention (Sullivan et al., 2007). On the other hand, neuroticism and conscientiousness are respectively associated with the effectiveness of sirbutramin and orlitstat pharmacological weight loss

therapies (Gerlach et al., 2015). Low conscientiousness and high neuroticism, in particular, have been associated with higher body mass index (BMI) (Sutin and Terracciano, 2017) and poorer health outcomes (Atherton et al., 2014). High neuroticism has been found to enhance the effect of polygenetic predisposition toward overweight and obesity (Clarke et al., 2015), and it has been associated with inflammatory indices and other environmental/social risk factors relating to obesity (Sutin and Terracciano, 2017). The tendency toward less physical activity and/or more sedentary behaviours observed in highly neurotic people has also been proposed to be at least partially responsible for the association with BMI (Kjelsas and Augestad, 2004; Sutin and Terracciano, 2016, 2017). Conflicting evidence has however been reported. Some studies (n = 11 554; n = 1 495 and n = 30 722,

respectively) have shown low neuroticism to be associated with higher BMI (Kakizaki et al., 2008; Otonari et al., 2012; Shim et al., 2014), while a Danish study (n = 5 286) has failed in finding any association between BMI and neuroticism in either men or women (Wimmelmann et al., 2018). Psychological and psychiatric comorbidities might partially explain the discrepancies across studies (Paans et al., 2016). Moreover, other unrelated factors, such as the work dimension, and in particular the physical workload, have been found to interact with neuroticism in influencing BMI (Blanch and Aluja, 2013). The association between BMI and personality seems also to differ remarkably between genders, and is more consistent in women rather than men (Sutin and Terracciano, 2016, 2017). Finally, it is worth noticing that the ethnicity of the participants varies between studies, as the samples included Asian (Kakizaki et al., 2008; Otonari et al., 2012; Shim et al., 2014), European (Wimmelmann et al., 2018) or multi-ethnical participants (Sutin and Terracciano, 2016).

In recent years, a growing body of research has linked personality traits to cognitive performance (Burles et al., 2014; Caselli et al., 2016; Chapman et al., 2017; Dar-Nimrod et al., 2012; Munoz et al., 2013; Robison et al., 2017; Waggel et al., 2015; Wettstein et al., 2016). In particular, low neuroticism has been associated to a better executive function in middle-aged (Caselli et al., 2016; Robison et al., 2017) and elderly adults (Chapman et al., 2017; Waggel et al., 2015). Remarkably, executive function has been reported to predict the health behavior of the individuals more accurately than neuroticism (Hall et al., 2014), and reduced executive function has been associated with neuroticism and two lifestyle risk factors for obesity, namely sedentary behavior and fatty food consumption (Hall et al., 2014). The factors underlying this association are still unclear. Increased cortisol is associated with both specific personality traits and worse cognitive performance (Ouanes et al., 2017), however it does not seem to be mediating the link between personality and cognition (Ouanes et al., 2017). Nonetheless, the intertwining between executive function and neuroticism might play a role in predisposing to obesity development. In fact, obesity has been linked to an impairment in executive function (Dassen et al., 2018), and therapies targeting executive function seem to meliorate health behaviors in obese people by improving their cognitive flexibility (Allom et al., 2018). On the other hand, overweight people are understudied, and evidence is lacking regarding the existence of executive functions impairments in these population (Yang et al., 2018). Moreover, information are lacking regarding overweight individuals' cognitive performance on other domains, such as fluid intelligence, which has also been found to be impaired in obesity (Spyridaki et al., 2014). Nonetheless, overweight in mid-life has been related to lower short-term memory performance in later life (Hassing et al., 2010). Accordingly, high BMI has been related to accelerated cognitive aging (Kirton and Dotson, 2016).

In this study, we examined cross-sectional associations of neuroticism and cognitive function with overweight and obesity in a sample of 170 310 individuals from the UK Biobank cohort, adjusted for life-style factors. Different cognitive domains were explored with the use of several tasks. In particular, measures on fluid intelligence (FI) (reasoning ability), trail making test (TMT) (executive function (Arbuthnott and Frank, 2000; Salthouse, 2011)), numeric memory test, and pairs matching (PM) task were acquired. Correlations between neuroticism and cognitive performance were also investigated. Furthermore, we investigated whether neuroticism and executive function could predict BMI changes over time.

2. Methods

2.1. Subjects: the UK Biobank cohort

The UK Biobank cohort (http://www.ukbiobank.ac.uk/) is a longitudinal cohort, with three different assessments carried out between 2006-present. The participants were invited for data collection at one of

the 22 assessment centers throughout UK. Ethical approval to conduct UK Biobank baseline data collection was granted by North-West Multicentre Research Ethics Committee, and this study was further approved by the Regional Ethics Committee of Uppsala, Sweden. Written consent was obtained from all participants, and could be withdrawn at any time. For each of the variable of interest, a detailed description can be found on the UK Biobank website (Data Showcase: http://biobank.ctsu.ox.ac.uk/crystal/label.cgi). For reproducibility reasons, we report the field ID of each variable as coded on the UK Biobank website.

Information regarding the following variables were extracted from the dataset: neuroticism score (Field ID: 20127), age (Field ID: 21003), gender (Field ID: 31), BMI (Field ID: 21001), ethnic background (Field ID: 21000), qualification (Field ID: 6138), smoking status (Field ID: 20116), alcohol intake frequency (Field ID: 1558), physical activity. Cognitive performance data were acquired on the TMT (Fields IDs: 20156, 20157), FI (Field ID: 20016), PM (Field ID: 399) and numeric memory task (Field ID: 4282). For all the variables, the answers "I don't know" and "Prefer not to answer" were recoded as system missing.

151 310 participants with pre-existing psychiatric diseases or neurological according to the ICD-10 classification (Field ID: 41202) were excluded from the baseline analysis. 348 690 participants were retained.

2.2. Description and preparation of outcome and predictor variables

BMI was calculated based on height and weight measured at the Assessment Centre. We classified the participants into three categories according to their BMI: normal weight (BMI: $18.5 \, \text{kg/m}^2$ to $24.9 \, \text{kg/m}^2$); overweight (BMI: $25 \, \text{kg/m}^2$ to $29.9 \, \text{kg/m}^2$); obese (BMI $\geq 30 \, \text{kg/m}^2$). BMI was acquired at three time-points: the first assessment took place between 2006 and 2010; the second assessment was carried out between 2012 and 2013 (time interval between 1 and 4 years); the third assessment was carried out after 2014 (time interval between 5 and 10 years from baseline).

Neuroticism score was derived by the sum of 12 neurotic behavioral domains, as provided by the UK Biobank. In particular, the participants had been asked to answer questions regarding their tendency to experience mood swings (Field ID: 1920; "Does your mood often go up and down?"), miserableness (Field ID: 1930; "Do you ever feel 'just miserable' for no reason?"), irritability (Field ID: 1940; "Are you an irritable person?"), sensitivity/ hurt feelings (Field ID: 1950; "Are your feelings easily hurt?"), fed-up feelings (Field ID: 1960; "Do you often feel 'fed-up'?"), nervous feelings (Field ID: 1970; "Would you call yourself a nervous person?"), worrier/anxious feelings (Field ID: 1980; "Are you a worrier?"), a sensation of being tense/ 'highly strung' (Field ID: 1990; "Would you call yourself tense or 'highly strung'?"), worry too long after embarrassment (Field ID: 2000; "Do you worry too long after an embarrassing experience?"), suffer from 'nerves' (Field ID: 2010; "Do you suffer from 'nerves'?"), loneliness/isolation feelings (Field ID: 2020; "Do you often feel lonely?"), and guilty feelings (Field ID: 2030; "Are you often troubled by feelings of guilt?"). The answers "Yes" and "No" were respectively assigned the values of 1 and 0, and the scores were summed up to obtain the neuroticism score.

Short-term memory was assessed with the PM and numeric memory tests. The PM test consisted in instructing the participants to memorise the position of as many matching pairs of cards as possible. The cards were then turned face down on the screen, and the participants were asked to touch as many pairs as possible in the fewest tries. Two rounds were conducted, the first round using 3 pairs of cards and the second 6 pairs of cards. As recommended by the UK Biobank website, the number of incorrect matches in round (Field ID: 399) was used as outcome variable. Only the second round, more challenging and with more variability in the responses, was considered in the present study. For the assessment of short-term numeric memory, the participants were shown a two-digit number and they were asked to remember it after a brief

pause. The procedure was followed until the participant made an error or if they had remembered the maximum of twelve digits. The maximum number of digits remembered correctly was considered in this study.

Reasoning ability was measured using the fluid intelligence test, assessed with a touch-screen questionnaire consisting of 13 items. The total score obtained by the participants was considered in this study. Finally, for the TMT, the participants were presented with a series of labelled circles and instructed to touch them according to a particular ordering rule. The test consists of two parts: in the first one (path A), less challenging, the labels are represented solely by numbers; in the second part (path B), alphanumeric labels are assigned to the circles. The duration to complete both paths was recorded. We derived the TMT ratio (B/A) as a measure of executive function (Salthouse, 2011), where a high TMT ratio reflected a worse performance.

2.3. Covariates

Age was assessed based on the date of birth and the date of attending the assessment centre, truncated to whole year part. The ethnic background was chosen from an amalgam of sequential branching questions. We grouped the answers in order to reduce the number of possible backgrounds to six categories, corresponding to the "top" categories of each branch: white, mixed, Asian or Asian British, black or black British, Chinese, other ethnic groups. To assess education, the participants were asked to select which qualifications they possessed amongst: college/university degree, A/AS levels or equivalent, O/GCSEs levels or equivalent, CSEs or equivalent, NVQ/HND/HNC or equivalent, other professional qualifications, none of the above. Participants could select more than one answer. Qualifications were recoded as a binary variable, based on whether the participants held or not a college/university degree.

Smoking status was coded as current smoker, previous smoker, or never smoked. To assess alcohol intake frequency, participants were asked to report whether they consumed alcohol: daily or almost daily, three or four times a week, once or twice a week, one to three times a month, on special occasions only, or never. Touchscreen-based questions were used to assess physical activity. The questions pertained the weekly frequency and duration (in minutes) of the walking, moderate physical activity and vigorous physical activity sessions, similarly to the short form of the International Physical Activity Questionnaire. The answers less than zero and greater than 1 440 were discarded during the data quality check performed by the UK Biobank; additionally, the participants were asked to reconfirm if their answer was greater than 300. We then calculated the total metabolic equivalent per time (MET) values for each category, by using the coefficients obtained from the International Physical Activity Questionnaire short form (3.3 for walking, 4.0 for moderate physical activity, and 8.0 for vigorous physical activity). MET scores (minutes/week) were derived by the following formula: (No. of days per week of walking 10+ minutes* duration of walks* 3.3) + (No. of days per week of moderate physical activity 10+ minutes * duration of moderate physical activity* 4) + (No. of days per week of vigorous activity 10+ minutes * duration of vigorous physical activity* 8) (Bradbury et al., 2017).

2.4. Data quality check

Extreme outliers, defined as having a z-score out of the range of ± 3.29, were checked on duration of walks (Field ID: 874), duration of moderate physical activity (Field ID: 894) and duration of vigorous physical activity (Field ID: 914), prior to computing the METs. After outliers removal, and removal of individuals with missing data on any of the covariates to be used in the reduced model (see below), the final sample consisted of 170 310 participants (Table 1).

Table 1
Sample descriptives.

	Mean (SD)	Missing values
Age *(years)*	55.8 (8.2)	
BMI *(kg/m²)*	26.8 (4.3)	0.26%
METs scores	3 326.1 (2 889.3)	
Pairs matching *(incorrect matches)*	4.1 (3.3)	
Fluid intelligence	6.3 (2.1)	65.2%
Trail making test ratio	1.8 (0.5)	75.0%
Numeric memory *(max digits remembered)*	7 (1.5)	73.2%
Neuroticism	3.8 (3.2)	13.7%
	Frequency	
Gender *(males; females)*	47.8%; 52.2%	
Qualification *(university/college degree)*	40.5%	0.3%
Ethnic background *(white)*	96.3%	0.2%
Smoking status *(current smokers)*	7.7%	0.2%
Alcohol intake frequency *(never)*	5.1%	0.01%

2.5. Statistical analysis

The Statistical Package for Social Sciences (SPSS, v.24: https://www.ibm.com/analytics/data-science/predictive-analytics/spss-statistical-software) was used for statistical analyses. A series of separate multinomial logistic regression models were performed to investigate associations of BMI with neuroticism and cognitive performance on the numeric memory, FI, PM and TMT tests. Two models were carried out for a sensitivity analysis. The first model was corrected for age, gender, education and ethnical background. The second model was additionally corrected for smoking status, alcohol intake frequency, and physical activity. The threshold for significance was set at p < 0.01 for the cross-sectional analysis to correct for multiple testing according to Bonferroni's approach (0.05/5 tests). Based on previous literature, we also tested for an effect of the interaction between neuroticism and gender on BMI. Furthermore, we investigated whether age could influence the association between BMI and neuroticism or cognitive function by also testing for the effect of the age*cognition interaction on BMI. The threshold for significance was set at p < 0.012, to correct for multiple testing (0.05 / 4 tests).

Additionally, we ran five generalized linear models (gamma with log-link) to investigate whether BMI, when treated as continuous instead of categorical, still showed the same pattern of associations with neuroticism and cognitive function. The same two abovementioned models were run. The threshold for significance was again set at p < 0.01 for the cross-sectional analysis to correct for multiple testing according to Bonferroni's approach.

Correlations between neuroticism score and each of the cognitive tests were investigated via separate models according to the distribution of the dependent variables. ANOVA was used to test correlations with FI and PM (Glass et al., 1972; Harwell et al., 1992; Lix et al., 1996), while correlations with numeric memory were assessed with a negative binomial generalized linear model, and correlations with TMT were assessed with a gamma generalized linear model. The threshold for significance was set at p < 0.013, to correct for multiple testing according to Bonferroni. The same abovementioned adjusted models were used.

Individuals with high neuroticism tend to vary their weight more than individuals with lower neuroticism levels, in terms of decreases as well as increases in BMI (Sutin et al., 2011; Sutin and Terracciano, 2017). Thus, we investigated correlations between neuroticism and BMI variation over time. BMI variation was calculated by subtracting the baseline BMI from the BMI at each follow-up point, and considering the absolute value of the variation. As executive function has been reported to predict the health behavior of the individuals more accurately than neuroticism (Hall et al., 2014), we also investigated correlations between executive function and BMI variations. To this purpose, separate ANOVAs were carried out to test whether baseline neuroticism and

Table 2
Cross-sectional associations of BMI with neuroticism and cognitive function.

	B	S.E.	Sig.	Exp (B)	C.I. (min, max)
Neuroticism					
Overweight vs lean	−0.011	0.002	7.2×10^{-8} *	0.989	0.986, 0.993
Obese vs lean	−0.004	0.002	0.133	0.996	0.992, 1.001
Overweight vs obese	−0.007	0.002	**0.003 ***	0.993	0.989, 0.998
Fluid Intelligence					
Overweight vs lean	−0.014	0.005	**0.006 ***	0.986	0.977, 0.996
Obese vs lean	−0.021	0.006	**0.001 ***	0.980	0.968, 0.992
Overweight vs obese	0.007	0.006	0.243	1.007	0.995, 1.019
Numeric Memory					
Overweight vs lean	−0.028	0.007	**0.0002 ***	0.973	0.959, 0.987
Obese vs lean	−0.065	0.010	6.8×10^{-11} *	0.937	0.919, 0.956
Overweight vs obese	0.037	0.010	**0.0002 ***	1.038	1.018, 1.058
Trail Making Test Ratio					
Overweight vs lean	0.027	0.022	0.215	1.027	0.985, 1.071
Obese vs lean	0.077	0.029	**0.007 ***	1.080	1.021, 1.142
Overweight vs obese	−0.050	0.028	0.072	0.951	0.900, 1.004
Pairs Matching					
Overweight vs lean	−0.009	0.002	1.2×10^{-7} *	0.991	0.987, 0.994
Obese vs lean	−0.022	0.002	9.0×10^{-23} *	0.978	0.974, 0.982
Overweight vs obese	0.013	0.002	1.8×10^{-9} *	1.013	1.009, 1.017

Adjusted for: age, gender, education, ethnical background, smoking status, alcohol consumption, physical activity.

TMT ratio could predict BMI variations at each of the two follow-up points. The same abovementioned models, reduced and fully-adjusted, were applied. The threshold for significance was set at p < 0.025 to correct for multiple testing.

3. Results

3.1. Lower neuroticism in overweight compared with normal weight and obese individuals

Neuroticism had a significant association with BMI at the cross-sectional analysis (p < 2.4×10^{-7}, n = 145 102), which remained significant after further correcting for physical activity, smoking status, and alcohol consumption (p < 2.6×10^{-7}; n = 144 906) (Table 2). In particular, lower neuroticism scores were associated to a greater probability of being overweight rather than lean (p < 7.2×10^{-8}) or obese (p < 0.003). No interactions between gender and neuroticism were found at the reduced (p < 0.147) and fully-adjusted models (p < 0.135).

3.2. Cognitive performance is reduced in overweight and obese individuals

Fluid intelligence was significantly associated with BMI (p < 0.0001; n = 58 412), even in the fully adjusted model (p < 0.001; n = 58 328). In particular, lower fluid intelligence was associated to being overweight (p < 0.006) or obese (p < 0.001) rather than lean. The same trend was observed for numeric memory, which was significantly associated with BMI in both the reduced (p < 2.7×10^{-10}; n = 45 146) and fully-adjusted models (p < 3.8×10^{-10}; n = 45 088). Again, lower numeric memory enhanced the probability of being overweight (p < 0.0002) or obese (p < 6.8×10^{-11}) rather than lean. Moreover, it was associated with

higher risk for being obese rather than overweight (p < 0.0002).

The TMT ratio was significantly associated to BMI (p < 0.011; n = 42 154), even in the fully-adjusted model (p < 0.028; n = 42 102), though it did not survive the correction for multiple testing. Finally, PM was also significantly associated to BMI (p < 1.5×10^{-21}; n = 167 997), even in the fully-adjusted model (p < 2.5×10^{-22}; n = 167 730). In particular, a higher number of incorrect matches (worse performance) was associated with being overweight rather than lean (p < 1.2×10^{-7}) or obese (p < 1.8×10^{-9}), and with being obese rather than lean (p < 9.0×10^{-23}). Details regarding the associations between cognitive scores and BMI are reported in Table 2.

No interaction effect between age and PM (p < 0.391 and p < 0.294), FI (p < 0.209 and p < 0.220), numeric memory (p < 0.774 and p < 0.754) and TMT ratio (p < 0.047 and p < 0.043) were found at the reduced model and adjusted model, respectively.

3.3. BMI as continuous is associated with cognition, but not with neuroticism

BMI, when treated as continuous, was not associated with neuroticism at the reduced model (p < 0.456), however it showed a significant positive association with neuroticism (p < 0.001) when further correcting for smoking status, alcohol consumption and physical activity (Table 3). However, the effect size was so small (η^2 = 0.000074) that any biological significance of this association as such can hardly be advocated. This was somewhat expected, given that the relationship appears not to be linear, as neuroticism is lower in overweight compared to controls, but no different between obese people and controls.

BMI also showed a significant positive correlation with PM performance (p < 1.3×10^{-27} and p < 7.9×10^{-29}) and TMT ratio

Table 3
Cross-sectional associations of BMI as continuous with neuroticism and cognition.

	B	S.E.	Sig.	η^2	C.I. (min, max)
Neuroticism	−0.011	0.003	**0.001 ***	0.00007	−0.018, -0.005
Fluid Intelligence	−0.027	0.009	**0.002 ***	0.0016	−0.044, -0.009
Numeric Memory	−0.100	0.013	2.8×10^{-14}*	0.001	−0.125, -0.074
Trail Making Test Ratio	0.131	0.038	**0.001***	0.0003	0.056, 0.205
Pairs Matching	−0.035	0.003	7.0×10^{-29}	0.001	−0.041, -0.029

Adjusted for: age, gender, education, ethnical background, smoking status, alcohol consumption, physical activity.
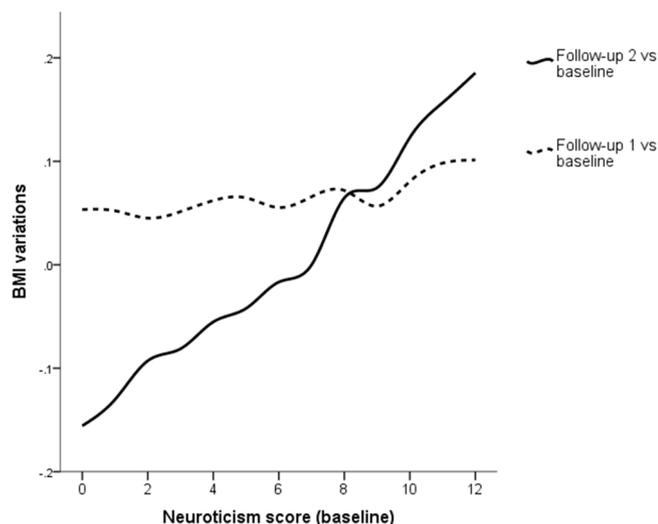
Fig. 1. Baseline neuroticism score predicts long-term BMI variations. The figure represents the association between baseline neuroticism score and BMI variations over time. The BMI variation was calculated as the BMI differences (absolute value) between baseline and follow-up 1 (1–4 years interval; dotted line) and between baseline and follow-up 2 (5–10 years interval; continuous line). Neuroticism score could predict long-term ($p < 0.017$; B = 0.021, CI (95%): 0.004-0.037), but not short-term ($p < 0.815$) BMI variations over time. The unstandardized predicted values derived from the univariate analysis are plotted against baseline neuroticism score.

($p < 0.0002$ and $p < 0.001$) in both models, though with a very small effect size ($\eta^2 = 0.001$ for PM and $\eta^2 = 0.0003$ for TMT ratio). BMI was also negatively associated with numeric memory in both models ($p < 2.4 \times 10^{-14}$ and $p < 2.8 \times 10^{-14}$) though with small effect size ($\eta^2 = 0.001$), and negatively associated with FI ($p < 0.00008$ and $p < 0.00008$), again with very small effect ($\eta^2 < 0.001$) (Table 3).

3.4. Correlations between neuroticism and cognitive performance

Neuroticism showed a significant negative correlation with FI ($p < 1.7 \times 10^{-13}$; n = 51 225), and a positive correlation with the TMT ratio ($p < 6.7 \times 10^{-10}$; n = 37 181) and the number of incorrect matches on PM ($p < 2.6 \times 10^{-32}$; n = 146 321), while it was not associated with numeric memory ($p < 0.368$; n = 39 812) at the reduced model. When further correcting for life-style related variables, neuroticism was still negatively correlated to FI ($p < 4.2 \times 10^{-14}$; n = 51 155) and positively correlated to the TMT ratio ($p < 2.9 \times 10^{-9}$; n = 37 140) and PM ($p < 2.7 \times 10^{-33}$; n = 146 125), while still no correlation was detected with numeric memory ($p < 0.335$; n = 39 765) (Fig. 2).

3.5. Neuroticism, but not executive function, is associated to BMI variations over time

Neuroticism was not associated with BMI variations in the short term ($p < 0.714$; n = 6 901), but it was associated with BMI variations in the long-term ($p < 0.017$; n = 4 292; B = 0.020, CI (95%): 0.004-0.037) (Fig. 1). On the other hand, the TMT ratio did not predict BMI variations at either follow-up points.

4. Discussion

In this study, we examined cross-sectional associations of neuroticism and cognitive function with overweight and obesity in a sample of 170 310 individuals from the UK Biobank cohort. We report that lower neuroticism is associated with being overweight rather than lean or

obese independently of gender, and that the baseline neuroticism score could predict BMI variations over time. Moreover, lower cognitive performance on reasoning, short-term memory, and executive domains was associated with being overweight or obese rather than lean. Finally, high neuroticism scores were associated to worse cognitive performance on all domains, except for numeric memory.

Psychological status has been previously suggested to be linked to greater weight variations over time (Pacanowski et al., 2018). A high neuroticism in particular has been related to greater BMI variability (Sutin and Terracciano, 2017), which is a risk factor for overweight and obesity development (Li et al., 2015). While we support the role of high neuroticism in determining greater long-term weight variations over time, no cross-sectional association with obesity was observed in our sample. Contrarily, low neuroticism was associated with overweight independently of other life-style factors, such as smoking, alcohol consumption and physical activity. Previous studies have reported conflicting evidence regarding the association between neuroticism and BMI. High neuroticism scores have been associated with obesity (Sutin et al., 2011), however studies including also overweight participants showed opposite results (Kakizaki et al., 2008; Shim et al., 2014). The confounding effect of other co-existing personality constructs has been suggested to play a role in determining these discrepancies (Shim et al., 2014). A lack of power has also been advocated as responsible (Kakizaki et al., 2008) for previous negative findings of no association between neuroticism and obesity (Hallstrom and Noppa, 1981). Our study, however, would be expected to have sufficient power to detect potential associations. Therefore, it seems reasonable that other underlying factors might modulate the relationship between neuroticism and BMI. Alternatively, the association between neuroticism and obesity might be biased by the greater BMI variability associated to high neuroticism (Sutin et al., 2011; Sutin and Terracciano, 2017), as supported by our findings. As BMI in the population tend to be skewed toward higher values, the high BMI variability linked to neuroticism might lead to the detection of cross-sectional association when the sample is not sufficiently large. Nonetheless, more evidence is needed to further elucidate the role of neuroticism and other personality constructs in influencing weight regulation and feeding behavior.

Obesity has been previously linked to worse cognitive performance on several domains (Prickett et al., 2018), while more limited research exists regarding overweight individuals. Impairments in FI have been reported in obese individuals (Spyridaki et al., 2014). Additionally, we show that lower FI is also associated with overweight. Lower short-term memory, as measured by the numeric memory and PM tests, was also associated with being overweight or obese, and a worse performance was associated with obesity compared to overweight, in line with previous reports of reduced visual memory in obese (Bove et al., 2016) and overweight individuals (Eneva et al., 2017; Stingl et al., 2012). Interestingly, being overweight in mid-life has been related to lower short-term memory performance in later life (Hassing et al., 2010) and to an enhanced risk for dementia (Hassing et al., 2009). Reduced executive function, on the other hand, was associated with obesity, but not with overweight in our sample. This is in line with a recent meta-analysis, which did not support the existence of executive function deficits in overweight individuals (Yang et al., 2018). Moreover, it is worth noticing that, when further adjusting for life-style factors, the association between obesity and the impairment in executive function seemed to be reduced, suggesting that life-style might partially influence this relationship.

Overall, our findings indicate that decreased FI, numeric memory and visual memory are associated with overweight, though generally with a lesser extent compared to obesity. A high BMI has indeed been linked to an acceleration in cognitive aging processes (Kirton and Dotson, 2016), maybe due to low-grade chronic inflammation and changes in the gut-brain axis (Solas et al., 2017). At least for FI, in fact, the worse performance observed in obese individuals has been related to the existence of a chronic low grade inflammation (Spyridaki et al.,
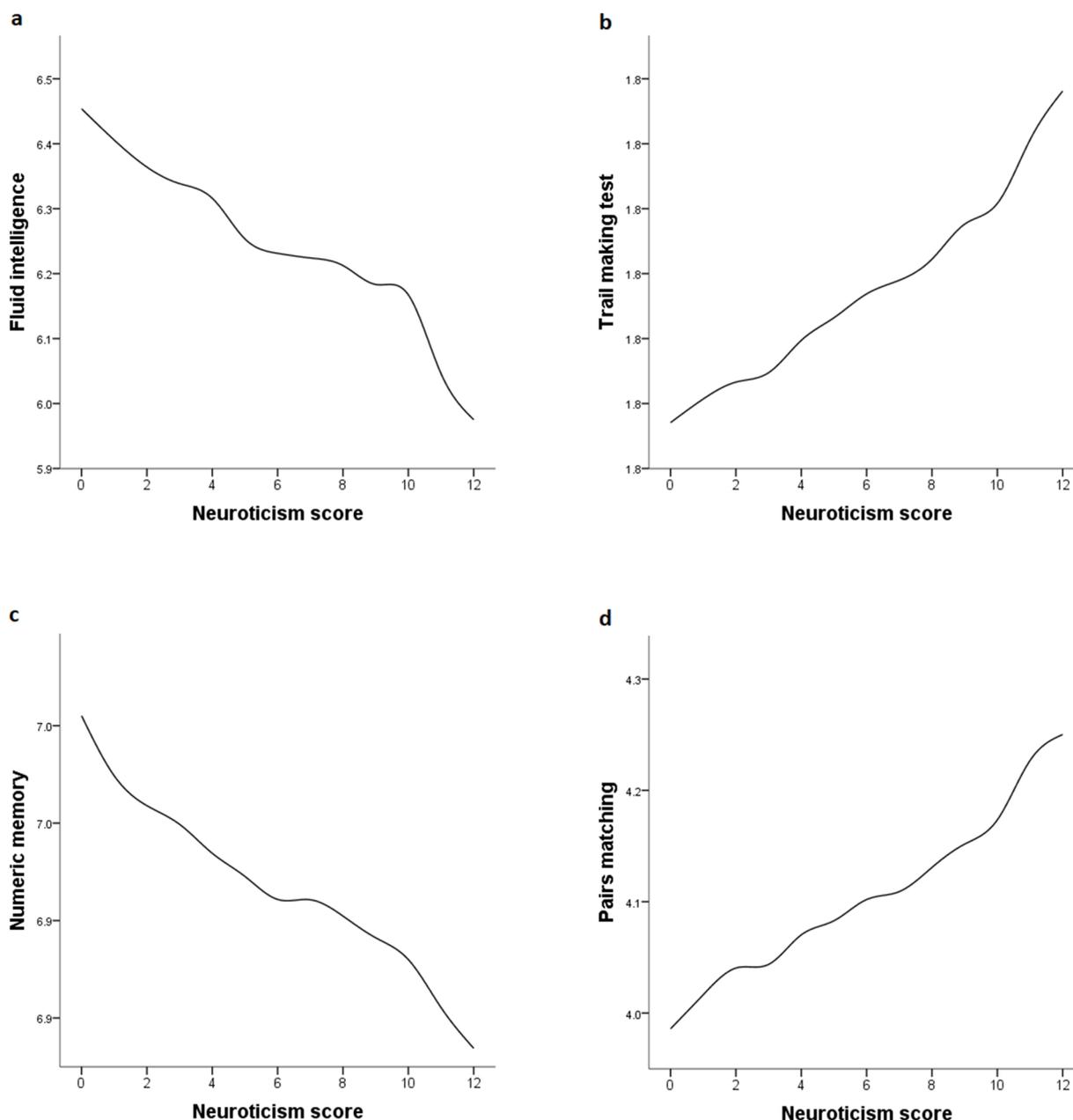
Fig. 2. Correlations between neuroticism and cognitive performance. The figure represents the correlations between neuroticism score and cognitive performance on the fluid intelligence (a), trail making test (b), numeric memory (c) and pairs matching (d). The unstandardized predicted values derived from the univariate analyses are plotted against the baseline neuroticism score. The models were corrected for age, gender, ethnical background, qualification, alcohol intake, smoking status and physical activity. Neuroticism showed a significant negative correlation with (a) FI ($p < 4.2 \times 10^{-14}$; n = 51 155) and positive correlations with (b) the TMT ratio ($p < 2.9 \times 10^{-9}$; n = 37 140) and (d) PM ($p < 2.7 \times 10^{-33}$; n = 146 125), while no correlation was detected with (c) numeric memory ($p < 0.335$; n = 39 765).

2014). Inflammation has been observed in overweight people as well (Murray et al., 2015), though with conflicting reports (Riyahi et al., 2018). However, it is worth noticing that personality traits have also been possibly associated with worse executive performance (Ouanes et al., 2017), and low neuroticism has been previously associated to a better executive function in middle-aged (Caselli et al., 2016; Robison et al., 2017) and elderly adults (Chapman et al., 2017; Waggel et al., 2015). Accordingly, low neuroticism scores were associated to a better cognitive performance on FI, PM, and TMT ratio in our sample. Longitudinal studies examining in depth the synergic effect of inflammation and personality traits on cognitive performance are however needed to shed light on the determinants of the lower cognitive performance observed in individuals with increased BMI.

Our study has a large sample size and a longitudinal as well as cross-sectional design. However, it also has some limitations. The data were derived from an external cohort, therefore we had to rely on the quality assessment made by the UK Biobank operators. Additionally, some of the variables included in this analysis were self-reported, included the neuroticism measurement. Moreover, the scale used to measure neuroticism in the UK Biobank is not a standard scale, and is more focused on anxiety, depressive and mood-related aspects rather than impulsivity. Finally, the UK Biobank population is reported to be generally more health-conscious than the general population (http://www.ukbiobank.ac.uk/2017/07/comparing-uk-biobank-participants-with-the-general-population/). It must also be noticed that the response rate to UK Biobank invitation was around 10% for the pilot (Watts, 2007),

but dropped to 5.5% when the real project was started (Swanson, 2012). It has thus been argued that this might lead to false positive associations findings, in particular when investigating comorbidities associations (Swanson, 2012). Thus, any generalization of our results should be made cautiously.

5. Conclusions

We examined cross-sectional associations of neuroticism and cognitive function with overweight and obesity in a sample of 170 310 individuals from the UK Biobank cohort. We report the association of reduced fluid intelligence and short-term memory with overweight and obesity. On the other hand, reduced executive function was associated with obesity, but not with overweight. Neuroticism scores correlated well with cognitive performance, supporting the link between personality traits and cognition. Moreover, we report that lower neuroticism is associated with being overweight rather than lean or obese independently of gender, and that baseline neuroticism scores could predict BMI variations over 5–10 years. We thus support the hypothesis that neuroticism might be associated to higher BMI variability rather than obesity per se. There is however a need for future studies to explore more in detail the role of other personality traits in modulating the associations between neuroticism, cognitive function and BMI.

Competing interests

The authors have no conflicts of interest to disclose.

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