Title: Quantifying bias in psychological and physical health in the UK Biobank imaging sub-sample.

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Abstract

UK Biobank is a prospective cohort study of around half-a-million general population participants, recruited between 2006 and 2010, with baseline studies at recruitment and multiple assessments since. From 2014 to date magnetic resonance imaging (MRI) has been pursued in a participant sub-sample, with the aim to scan around n=100k. This sub-sample are studied widely and therefore understanding their relative characteristics is important for future reports. We aimed to quantify psychological and physical health in the UK Biobank imaging sub-sample, compared with the rest of the cohort.

We used t-tests and chi-squares for continuous/categorical variables respectively, to estimate average differences on a range of cognitive, mental and physical health phenotypes. We contrasted baseline values of participants who attended imaging (vs. had not), and compared their values at the imaging visit vs. baseline values of participants who were not scanned. We also tested the hypothesis that the associations of established risk factors with worse cognition would be underestimated in the (hypothesized) healthier imaging group compared with the full cohort. We tested these interactions using linear regression models.

On a range of cognitive, mental health, cardiometabolic, inflammatory and neurological phenotypes we found that the 47,920 participants who were scanned by January 2021 showed consistent statistically significant 'healthy' bias compared with the ~450,000 who were not scanned. These effect sizes were small to moderate based on Cohen's d/Cramer's V metrics. We found evidence of interaction, where stratified analysis demonstrated that associations of established cognitive risk factors were smaller in the imaging sub-sample compared with the full cohort.

Of the ~100,000 participants who ultimately will undergo MRI assessment within UK Biobank, the first ~50,000 showed some 'healthy' bias on a range of metrics at baseline. Those differences largely remained at the subsequent imaging visit, and we provide evidence that testing associations in the imaging sub-sample alone could lead to potential underestimation of exposure/outcome estimates.

Introduction

Understanding and where possible addressing the effects of bias and confounding is a fundamental aim of human epidemiology. UK Biobank is a relatively large population cohort of around 0.5 million middle-aged to older adults recruited as generally healthy volunteers from England, Scotland and Wales. UK Biobank's 0.5 million participants reflect around a 5% response rate to initial invitations¹, with recognized recruitment bias where participants are relatively healthy (e.g. lower rates of smoking), well-educated and less deprived than the general UK population². This may have important implications for generalizability and extrapolating associations and exposure/outcome relationships to the broader population.

Most UK Biobank participants were between 40 to 70 years old at baseline assessment, which was completed from 2006-2010 when the mean age was around 60 years old. Since recruitment, a range of optional assessments have been offered/distributed to participants online via email (e.g. on diet preference, mental health etc.)¹. Further, from 2014, a sub-sample have been invited to attend magnetic resonance imaging (MRI) including of the heart, abdomen, and brain, with the eventual aim being to recruit around 100,000 participants from UK Biobank to imaging. At these visits, most of the baseline questionnaires and clinical assessments are also repeated³. In addition to the participation bias already noted in the cohort in baseline assessments at recruitment,² it has been shown that there is further participation bias with regard to completing additional online assessments (vs. attending only baseline) and that, to some extent, this participation bias has genetic contributions which vary by male/female sex^{4,5}.

Previous studies of bias in the UK Biobank population have focused on participation at all, and/or predictors of additional participation in subsequent online assessments^{4,5}. We are not aware of research which has explored differences in participants who subsequently attended for imaging studies. Within each geographic region where UK Biobank scanning centers are located, all cohort members are invited via email and post to attend unless they have opted out of such communications or have left the UK (<0.5% of participants³). Nevertheless, it might be expected that those who go on to attend would differ systematically from those who do not. This could be for several reasons including MRI contraindications like stents and pacemakers excluding less healthy participants, difficulties attending due to practical or health-

related factors, and less healthy participants at baseline being more likely to die before imaging began⁶.

We asked whether those who underwent imaging were healthier on average at baseline, and whether they remained so by the time of imaging. We also tested for interactions to investigate if (eventual) imaged status was an effect measure modifier; if this were the case, studies using only the imaging sample might underestimate established exposure/outcome associations compared with the full 502k cohort. This report quantifies differences in key cognitive, mental and physical health metrics (chosen *a priori*) in the imaging sub-sample.

Methods

Study design and participants

UK Biobank is a large prospective cohort study including 502,490 general population participants who attended one of 22 baseline assessment centres from 2006 to 2010 where they completed a series of physical, sociodemographic, and medical assessments¹. In 2014, MRI scanning of the heart, brain and abdomen for a sub-group of participants began, and this is ongoing with an eventual target sample size of 100,000. As of January 2021, MRI data were available on 47,920 participants who attended three centres (Cheadle; Newcastle; Reading) using identical protocols. An additional n=1069 participants were not deemed safe (2%) and were not included in the 'imaged' group. This project was completed using UK Biobank project #17689. For all variables we removed participants who chose not to answer/did not know (<5%).

Ethical approval

This secondary-data analysis study was conducted under generic approval from the NHS National Research Ethics Service (approval letter dated 13th May 2016, ref 16/NW/0274). Written informed consent was obtained from all participants recruited to UK Biobank.

Data availability statement

UK Biobank is an open access resource available to verified researchers upon application (<http://www.ukbiobank.ac.uk/>). Analysis syntax is available upon request.

Demographic data

Age, sex, ethnicity and educational attainment were self-reported. Townsend Deprivation Index was derived from postcode of residence⁷. This provides an area-based measure of socioeconomic deprivation derived from aggregated data on car ownership, household overcrowding, owner occupation and unemployment. Higher Townsend scores equate to higher levels of area-based socioeconomic deprivation.

Blood pressure and anthropometric data

Diastolic and systolic blood pressure (DBP; SBP) were assessed using digital blood pressure monitors (HEM-7015IT; Omron Healthcare Inc). We used the second reading because there is evidence the first reading can overestimate blood pressure⁸. Weight was measured, to the nearest 0.1 kg, using the Tanita BC-418 MA body composition analyser. Height was measured using a Seca 202 height measure. Body mass index (BMI) was derived as weight (kg)/(height (m)×height (m)) by UK Biobank centrally. Participants removed their shoes and heavy outer clothing before weight and height were measured.

Cognitive data

We examined tests that were included as part of the UK Biobank baseline cognitive assessment⁹. One of these was a task with thirteen logic/reasoning-type questions and a two-minute time limit labelled ‘fluid intelligence’ in the UK Biobank protocol but hereafter referred to as *verbal-numerical reasoning*. The maximum score was 13 where higher scores indicate better performance. *Pairs matching* was a visuospatial memory test, where participants were asked to memorize the positions of six card pairs, and then match them from memory while making as few errors as possible. We refer to this test as the memory task from here on. Scores on the memory test are for the number of errors that each participant made, and higher scores are, therefore, worse. For the *Prospective Memory* (PM) test, participants were asked to engage in a specific behaviour later in the assessment: ‘At the end of the games we will show you four coloured symbols and ask you to touch the blue square. However, to test your memory, we want you to actually touch the Orange Circle instead’. We scored participants as zero or one, depending on whether they completed the task on first attempt or not. Participants completed a timed test of symbol matching similar to the common card game Snap, which we refer to as the *reaction time* task; scores are

measured in milliseconds with higher values indicating worse performance. The PM and reasoning tests were added part-way through the baseline assessments and are therefore only in around one-third of baseline participants but were completed by most at imaging.

Psychological variables

Neuroticism was assessed using a point scale with values from 0 to 12, the Eysenck Personality Inventory Neuroticism scale - Revised (EPIN-R)¹⁰⁻¹². Depression (yes/no for lifetime history) was based on self-report. Participants self-reported their 'happiness' ordinally (extremely unhappy; very unhappy; moderately unhappy; moderately happy; very happy; extremely happy). This variable was added part-way through the baseline assessments and was completed then by around one-third of participants. We derived a dichotomous variable where participants were moderately/very/extremely unhappy vs. not.

Lifestyle

Participants self-reported their smoking history; current, past or never. We collated past and current smokers into 'ever' (vs. never). Participants self-reported their alcohol intake frequency on a 5-point ordinal scale from 'never' to 'daily or almost daily'. We derived a dichotomous variable ('regular drinkers' vs. not) of collated 'daily or almost daily', 'three or four times a week' and 'once or twice a week' vs. 'one to three times a month', 'special occasions only' and 'never'. We excluded participants from this specific variable if they reported having changed their alcohol intake due to health problems or doctor's advice¹³.

Physical health conditions (cardiometabolic; inflammatory; neurological)

Using self-report, participants responded to the touch-screen question 'Has a doctor ever told you that you have had any of the following conditions?' (high blood pressure; stroke; angina; heart attack). We collated heart attack and angina into coronary heart disease (CHD). Participants were also asked 'Has a doctor ever told you that you have diabetes?' via touch-screen¹⁴. During an interview with a trained staff member, participants noted their history of any other medical conditions, and from this we derived the phenotypes of any vs. none for inflammatory conditions (e.g. rheumatoid

arthritis), detailed in a previous open-access paper¹⁵, and neurological conditions⁹. Participants self-reported regular medication for cholesterol, blood pressure, diabetes, and/or take exogenous hormones, from which we derived a dichotomous variable (any vs. none). Participants self-reported their overall health as excellent; good; fair; poor. We derived two dummy variables: excellent/good vs. fair (good health), and poor vs. fair (poor health).

Analyses

We tested for unadjusted differences in baseline values (2006-2010) in people who had not been imaged as of January 2021, vs. baseline values in people who had been imaged. We also contrasted baseline values in the non-imaged group (i.e. 2006-2010) vs. values of imaged participants at the time of scan (2014-2020). Townsend did not receive repeat assessment at imaging, and some were only repeated in some participants so were excluded from analysis, e.g. 'Has a doctor ever told you that you have had any of the following conditions?' (<https://biobank.ndph.ox.ac.uk/ukb/field.cgi?id=6150>). For continuous variables we used T-tests to derive p-values, and report Cohen's d effect sizes (standardised mean difference where 0.2 is small, 0.5 is medium and 0.8 is large). Due to non-normal distributions we natural log-transformed the memory variable scores (+1) and reaction time tests. For categorical variables we used Chi-square tests and Cramer's V as a metric of standardised effect size (0.1 is small, 0.3 is medium and 0.5 is large). Given the duration between the baseline and imaging visits, as a secondary analysis we adjusted the imaging-concurrent vs. non-imaged baseline contrasts for age at time of assessment using linear/logistic regressions for continuous/binary variables respectively.

Using baseline data from the whole cohort, we used linear regression to estimate associations between established risk factors and cognitive performance, including testing for interactions with imaged status. The established risk factors we tested were self-reported doctor diagnoses of coronary heart disease (CHD), diabetes and high blood pressure¹⁴.

A small number of participants who attended the MRI visit were deemed not safe to scan; these were classified in the non-imaged group in all analyses (in line with the fact that many other people in the non-imaged group would not have volunteered for scanning or would have been screened out prior to the visit because of known

contraindications). We report uncorrected p-values throughout; as sensitivity analysis we correct final results for type-1 error using False Discovery Rate (FDR)^{16,17}.

Results

At baseline recruitment to UK Biobank there were n=502,490, participants, with an overall mean age=56.53 (SD=8.10) and 229,114 (45.60%) were male. Of those baseline participants, N=48,989 attended MRI by date of analysis, of which N=47,920 went on to be scanned, representing the 'MRI' sub-sample. The mean age of the MRI sub-sample at time of scan was 64.15 (SD=7.73) with the typical interval between baseline and imaging 8.98 (minimum 4, maximum 14, SD =1.8) years.

[Insert Table 1]

Baseline visit values

We first contrasted baseline values of people who were later imaged versus not. The imaged group showed consistently significant differences for lifestyle, psychological and cardiometabolic and demographic variables (see Table 1). The metrics of standardised effect size (Cohen's d for continuous variables; Cramer's V for dichotomous) varied from 0.02 for sex to -0.21 for Townsend; i.e. there was a statistically significant but effectively very small bias towards being female, and a larger but still small bias towards less deprivation in the imaged group. Other notable but still ultimately small effects were seen for younger age and lower BMI. In terms of psychological variables, all variables showed statistically significant differences, which ranged from Cohen's d=-0.08 (log visual memory errors) to reasoning (0.36). Overall, when compared to non-imaged participants at baseline, participants who went on to be imaged were: slightly younger (average 55 vs. 57 years); more likely to be female; more likely to have a degree; White British; less deprived; at lower risk of diabetes, hypertension, CHD, inflammatory and neurological conditions; less likely to self-report medication usage; have ever-smoke; had lower BMI and diastolic/systolic blood pressure, lower risk of depression, lower neuroticism, and show better cognitive scores. Most of these effect sizes were relatively small. Descriptive statistics are shown in Supplementary Table 1.

[Insert Table 2]Imaging visit values

Where possible we repeated the previous analyses but contrasting imaging-concurrent values vs. non-imaged participant baseline data. These are shown in Table 2, with descriptive statistics in Supplementary Table 2. Excluding age, which had a large effect due to being several years later, effect sizes were largely similar. All tests were statistically significant at $p < 0.05$ except for diabetes prevalence ($p = 0.628$). The largest effect sizes were found for diastolic BP (Cohen's $d = -0.36$; lower in imaging group), reasoning ($d = 0.32$; higher/better in imaging group) and (log) reaction time ($d = 0.34$; slower in imaging group). For depression and inflammatory conditions, the direction of association had changed where the imaging group had slightly higher rates. After adjusting additionally for age at time of assessment, all associations remained statistically significant to very similar degrees, except for 'unhappy' (vs. happy; $p = 0.245$).

Interaction tests: imaging status and established risk factors vs. cognitive scores

We tested the hypothesis of interaction between imaged status and known risk factors for baseline cognitive scores, cross-sectionally in the whole cohort. Models included continuous age, sex, imaged status, [risk factor] and ([risk factor] x imaged status). The models were run separately for log RT, log memory errors and reasoning scores. Overall, there were several interactions whereby the imaged group showed significantly smaller associations between established cardiometabolic risk factors and baseline cognitive scores, compared to the associations in the non-imaged group.

For CHD, interactions with imaged status were statistically significant for log RT and reasoning ($p < 0.001$) but not log memory errors ($p = 0.559$); indicative of differential associations of risk factors with cognitive abilities depending on whether participants were later imaged or not. The standardised beta estimate (β), reflecting differences in standard deviation (SD) units for CHD vs. log RT was significantly larger in the non-imaged sample ($\beta = 0.026$, $p < 0.001$) vs. imaged group ($\beta = 0.009$, $p = 0.046$). This was also the case for CHD and reasoning ($\beta = -0.047$, $p < 0.001$ non-imaged vs. -0.039 , $p < 0.001$ imaged).

For diabetes there were significant interactions for log RT and reasoning (both $p < 0.001$) but not log memory errors ($p = 0.095$). For log RT the association was larger

in non-imaged ($\beta = 0.040$, $p < 0.001$) vs. imaged (0.020 , $p < 0.001$) and similarly for reasoning: larger in non-imaged (-0.054 , $p < 0.001$) compared with imaged (-0.019 , $p = 0.014$).

For high blood pressure, the interaction terms were significant in all three models ($p < 0.001$): log RT (non-imaged $\beta = 0.029$, $p < 0.001$ vs. imaged $\beta = 0.016$, $p < 0.001$); log memory errors (non-imaged $\beta = 0.005$, $p = 0.001$ vs. imaged $\beta = 0.002$, $p = 0.697$); and finally reasoning (non-imaged $\beta = -0.052$, $p < 0.001$ vs. imaged -0.028 , $p = 0.001$).

Sensitivity analyses

We determined the BP results were unchanged when we added 10/15 mmHg to diastolic/systolic BP respectively¹⁸, for participant baseline/imaging values if they also reported antihypertensive medication. No association p-values attenuated when corrected for multiple testing with FDR. Study results were unchanged when we included the participants who volunteered for but did not complete imaging, in either the imaging and/or non-imaged groups. In addition to simply 'completed MRI', We restricted analysis to participants with useable data (based on <https://biobank.ndph.ox.ac.uk/showcase/field.cgi?id=25767>) which lowered sample size from $N=47,920$ to $N=32,778$. Findings were very similar, with effect sizes generally agreeing to the 2nd or 3rd decimal point (e.g. for reasoning the initial Cohen's $D = 0.36$ became 0.37).

Discussion

This study aimed to quantify and characterise differences between the sub-sample of approximately 50,000 UK Biobank participants who had completed imaging as of January 2021 and the wider UK Biobank cohort. Overall, our data demonstrate a degree of 'healthy bias' among imaged participants when compared to non-imaged participants with regards a range of psychological, cardiometabolic, cognitive, inflammatory, lifestyle and demographic variables. Participants who were subsequently imaged were shown to have healthier demographics and lifestyles (e.g. lower deprivation and smoking history), better psychological health (less depression; unhappiness; lower neuroticism;), better cognitive abilities (memory; reasoning; information processing speed) and physical health (lower prevalence of several different conditions; lower BP). This has value with regard to understanding selection

biases in a cohort already appreciated to have bias towards healthier individuals in the population and a restricted range on some key demographic variables.

The effect sizes for these differences were generally small to moderate. When we compared non-imaged participant baseline values (2006-2010) to measures taken at imaging (2014 to date) these effect sizes were generally consistent with those observed cross-sectionally at baseline. Exceptions included slightly increased rates of depression, chronic inflammatory conditions, and that the imaging group performed worse on the reaction time test. This survived correction for age at time of assessment. It is not clear why: this may reflect test imprecision, non-linear biological/cognitive ageing and accumulation not captured by the age at time of assessment value, and/or systematic differences in procedure at baseline vs. MRI, for example that the imaging visit cognitive assessment was longer, including tests not reported here⁶. This added length may contribute to fatigue. Reasoning scores remained better than the baseline group, which may reflect the presence of items in the test served by accumulated 'crystallized' intelligence⁹.

Implications

Volunteer bias in UK Biobank is recognized, in terms of participation at all vs. the general population, as well as between baseline and later optional online assessments^{2,5}. It has been noted that this raises the possibility of collider bias, which can distort estimates of exposure/outcome associations either towards or away from the null¹⁹. This report documents additional differences between the sub-group of UK Biobank participants who were subsequently imaged compared to those who were not as of January 2021. We show that if researchers were to analyse a known association¹⁴ – here cardiometabolic conditions vs. cognitive abilities – using only the imaging sub-sample, there is a risk they would underestimate the true magnitude of association. This supports the assertion that non-representativeness and selection bias can have a meaningful impact on interpretation and estimation of effect size²⁰. Where possible, researchers should incorporate data from the full UK Biobank cohort, seek replication cohorts, and acknowledge and adjust for potential healthy bias and restrictions of range²¹.

Limitations and future research

This study used data from around 50k participants with MRI data as of January 2021. The ultimate expectation is that 100k participants will undergo MRI scanning, and it will be informative to re-test these variables in that larger sample to see whether the biases identified here persist as the dataset grows. Future studies may investigate more fine-grained analyses e.g. use of fine-grained psychotropic medication history as a proxy for psychological health, and/or individual conditions rather than collated sets as were used here in some instances.

Conclusion

UK Biobank is a relatively large prospective research cohort which has been used extensively in recent years to investigate exposure/outcome associations at scale, across a wide variety of fields including psychiatry, cognitive ageing, dementia, inflammation, immunity, cancer and cardiology²². Since 2014 UK Biobank has assessed a sub-sample of the original 502k participants with MR imaging, with the aim of scanning 100k participants including some longitudinally²³. Here we show evidence for a small to moderate degree of healthy bias at baseline which mostly persisted at the time of imaging itself, when comparing participants who were scanned with those who were not (as of January 2021). This is over and above the healthy bias already present in the whole cohort at baseline compared to the general population. We show that testing exposure/outcome associations using only the imaging sample would lead to a significant underestimate of effect, which has important implications for the planning and interpretation of MRI studies in UK Biobank.

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Contributions

Concept and design: DML, BC.

Acquisition, analysis, or interpretation of data: DML, JW, LML, MEB, RJS, BC.

Drafting of the manuscript: DML.

Critical revision of the manuscript for important intellectual content: all co-authors.

Statistical analysis: DML.

Administrative, technical, or material support: all co-authors.

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Conflict of interest statement

The authors have no conflicts of interest to report.

Table 1: Non-imaged vs. imaged baseline values: demographic, lifestyle, psychological and physical health variables.

	t	df	p	Mean Difference	95% CI for Mean Difference		Cohen's d
					Lower	Upper	
Age in years	-38.724	502,488	<0.001	-1.503	-1.579	-1.427	-0.186
Sex (male N)*	132.469	1	<0.001	-0.111	-0.129	-0.092	0.016
Degree yes N*	4365.962	1	<0.001	-0.635	-0.654	-0.616	0.094
White British N*	416.475	1	<0.001	-0.342	-0.375	-0.309	0.029
Townsend score	-43.035	501,865	<0.001	-0.639	-0.668	-0.610	-0.207
Diabetes N*	668.37	1	<0.001	0.724	0.668	0.781	0.037
High blood pressure N*	1214.326	1	<0.001	0.41	0.387	0.433	0.049
Coronary heart disease N*	567.799	1	<0.001	0.714	0.654	0.774	0.034
Neurological condition N*	328.033	1	<0.001	0.509	0.454	0.565	0.026
Inflammatory condition, N*	631.573	1	<0.001	0.356	0.328	0.384	0.036
Medication use N*	740.545	1	<0.001	0.39	0.362	0.418	0.038
Smoking status (ever smoker) N*	672.739	1	<0.001	0.254	0.235	0.273	0.037
Alcohol frequency (≥weekly) N*	970.125	1	<0.001	-0.36	-0.383	-0.338	0.045
Diastolic blood pressure (mmHg)	-14.125	461,276	<0.001	-0.729	-0.830	-0.628	-0.071
Systolic blood pressure (mmHg)	-27.554	461,272	<0.001	-2.581	-2.764	-2.397	-0.138
Body mass index	-38.317	499,384	<0.001	-0.883	-0.929	-0.838	-0.184
Good/excellent health N*	1803.851	1	<0.001	-0.572	-0.599	-0.546	0.062
Poor health N*	242.253	1	<0.001	0.571	0.498	0.644	0.043
Verbal-numerical reasoning score	43.867	165,452	<0.001	0.782	0.747	0.817	0.364
Log reaction time	-40.482	496,663	<0.001	-0.037	-0.039	-0.035	-0.195
Reaction time in milliseconds	-39.888	496,663	<0.001	-22.612	-23.724	-21.501	-0.192
Log visual memory errors	-15.956	497,865	<0.001	-0.051	-0.057	-0.045	-0.077
Visual memory errors	-20.894	497,865	<0.001	-0.343	-0.375	-0.311	-0.101
Prospective memory, successful on first attempt N*	432.074	1	<0.001	-1.13	-1.243	-1.018	0.056
Unhappy N*	18.859	1	<0.001	0.18	0.099	0.262	0.01
Neuroticism score	-19.933	401,561	<0.001	-0.342	-0.375	-0.308	-0.105
Self-reported depression N*	78.898	1	<0.001	0.199	0.155	0.243	0.013

Note. Student's t-test for continuous variables. For dichotomous variables denoted by N*: $t = \chi^2$, mean difference = log odds ratio (difference), Cohen's d = Cramer's V. Mean difference reflects imaged group (i.e. imaged average – non-imaged average).

Table 2: Comparison of baseline values in the non-imaged group vs. imaging visit values.

	t	df	p	Mean Difference	95% CI for Mean Difference		Cohen's d
					Lower	Upper	
Age in years	192.182	502,488	<0.001	7.475	7.398	7.551	0.923
Diabetes N*	0.235	1	0.628	-0.01	-0.051	0.031	<0.001
Inflammatory condition, N*	163.087	1	<0.001	-0.156	-0.18	-0.132	0.018
Neurological condition N*	1458.624	1	<0.001	-1.035	-1.091	-0.98	0.057
Medication use, N*	10.149	1	0.001	0.041	0.016	0.066	0.005
Smoking status (ever smoker) N*	1128.722	1	<0.001	0.333	0.313	0.352	0.048
Alcohol frequency (≥weekly) N*	4546.902	1	<0.001	-0.903	-0.93	-0.876	0.097
Diastolic blood pressure (mmHg)	-66.757	455,124	<0.001	-3.699	-3.808	-3.591	-0.359
Systolic blood pressure (mmHg)	5.115	455,116	<0.001	0.515	0.318	0.713	0.028
Body mass index	-40.829	497,530	<0.001	-0.959	-1.005	-0.913	-0.200
Good/excellent health, N*	994.52	1	<0.001	-0.407	-0.433	-0.382	0.046
Poor health N*	247.755	1	<0.001	0.536	0.468	0.603	0.044
Verbal-numerical reasoning score,	58.665	193,423	<0.001	0.680	0.657	0.703	0.318
Log reaction time	68.365	493,482	<0.001	0.065	0.063	0.067	0.339
Reaction time in milliseconds	59.827	493,482	<0.001	35.251	34.096	36.406	0.297
Log visual memory errors	-26.991	495,485	<0.001	-0.088	-0.095	-0.082	-0.134
Visual memory errors	-30.531	495,485	<0.001	-0.513	-0.545	-0.480	-0.151
Prospective memory, successful on first attempt N*	47.545	1	<0.001	-0.168	-0.216	-0.12	0.017
Unhappy N*	133.65	1	<0.001	0.316	0.262	0.37	0.026
Neuroticism score	-67.671	408,823	< 0.001	-1.08	-1.112	-1.049	-0.33
Self-reported depression N*	31.989	1	<0.001	-0.112	-0.151	-0.073	0.008

Note. Student's t-test for continuous variables. For dichotomous variables denoted by N*: t =chi-square χ^2 , mean difference = log odds ratio (difference), Cohen's d = Cramer's V. Mean difference reflects imaged group (i.e. imaged average – non-imaged average).