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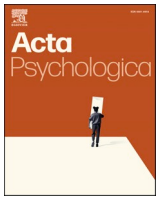

Whole-brain gray matter volume mediates the relationship between psychological distress and job satisfaction

Keisuke Kokubun [a,*], Kiyotaka Nemoto [b], Yoshinori Yamakawa [a,c,d,e,f]

[a] Graduate School of Management, Kyoto University, Kyoto, Japan
[b] Department of Psychiatry, Institute of Medicine, University of Tsukuba, Tsukuba, Japan
[c] Institute of Innovative Research, Institute of Science Tokyo, Meguro, Tokyo, Japan
[d] ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan), Chiyoda, Tokyo, Japan
[e] Office for Academic and Industrial Innovation, Kobe University, Kobe, Japan
[f] Brain Impact, Kyoto, Japan

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ABSTRACT

Individual differences in brain structure are not only seen between healthy and diseased individuals, or between young and elderly people, but also in middle-aged men and women. Previous studies have shown that the cause is related to psychological distress and stress, and that it is accompanied by a decline in performance. This suggests that among middle-aged male and female workers who consider themselves healthy, the brain may atrophy depending on the level of psychological distress, which may reduce job satisfaction. Therefore, in this study, we analyzed the relationship between brain structure and psychological variables from the analysis of brain images obtained by magnetic resonance imaging (MRI) and the results of a questionnaire survey of 80 middle-aged male and female workers who consider themselves healthy. The results showed that the gray matter of the whole brain, frontal lobe, temporal lobe, and parietal lobe mediated the relationship between psychological distress and job satisfaction. This suggests that more workers than previously believed may have symptoms like frontotemporal dementia (FTD) due to psychological distress, reducing their job performance and job satisfaction.

1. Introduction

Workers' stress and job satisfaction are closely related to their performance (Anasori et al., 2023; Katebi et al., 2022; Meunier et al., 2022; Riketta, 2008; Siu et al., 2004; Weiler, 2004). Therefore, their stress and job satisfaction are one of the most important topics in management and psychology. In brain research, several studies have also revealed the effects of occupational stress on the brain (Golkar et al., 2014; Savic, 2015). For example, Savic (2015) showed that chronic occupational stress is associated with significant thinning and volume loss in the proximal frontal cortex. Similarly, many studies have reported that individuals with burnout syndrome show changes in frontal brain regions (Blix et al., 2013; Durning et al., 2013; Liston et al., 2009). de Andrade et al. (2016) argued that burnout sufferers tend to use more "brain resources" to complete cognitive tasks.

The trend of research regarding the brain as a "resource" suggests the possibility of interdisciplinary research, because psychologists often explain the relationship between stress and behavior with the conservation of resources (COR) theory (Hobfoll, 1989). According to this theory, workers have a caravan of resources. Resources are depleted when used, but can also be replenished by recharging. The desire to keep resources constant motivates workers' behavior. In other words, if workers are dissatisfied with the amount and time at work, they will be exhausted by the consumption of resources such as physical energy and time with family, which will ultimately affect the organization by reducing productivity or increasing intention to quit. If the brain research shown above is applied to the COR theory, it can be interpreted that workers working in demanding workplaces have reduced brain resources, namely the cortex (de Andrade et al., 2016; Muraven & Baumeister, 2000).

Individual differences in brain conditions including gray matter volume (GMV) is also seen even among middle-aged people who feel healthy, regardless of age or whether they have a specific disease that causes symptoms, due to the fatigue and stress they feel (Kokubun et al.,

* Corresponding author.
E-mail address: kokubun.keisuke.6x@kyoto-u.jp (K. Kokubun).

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2018). In addition, it has been revealed that differences in GMV in healthy adults are related to differences in cognitive ability (Kokubun, Nemoto, & Yamakawa, 2020), social performance such as motivation, self-monitoring, and empathy (Kokubun et al., 2023), and ambidexterity such as persevering in one thing while being curious about many things (Kokubun, Yamakawa, & Hiraki, 2020). A recent pilot study has shown that differences in GMV are related to differences in diversity understanding, which may enable collaboration with others of different genders and origins in a globalized society (Otsuka et al., 2025). Furthermore, there is already a wealth of research in the fields of public health and management science showing that psychological distress and stress affect job performance (Anasori et al., 2023; Meunier et al., 2022; Siu et al., 2004). For example, a study of 374 construction workers at 27 construction sites in Hong Kong found that psychological distress predicted accident rates (Siu et al., 2004). Meanwhile, high job performance is often accompanied by high job satisfaction (Katebi et al., 2022; Riketta, 2008; Weiler, 2004). For example, an analysis of data from the European Working Conditions Survey showed that high-performance work practices positively impact job satisfaction (Weiler, 2004). Job satisfaction is one of the most important psychological indicators in the workplace, as it is related to turnover intentions (Anees et al., 2021; Hellman, 1997; Hua et al., 2023), among other things. As a result, there is a growing body of research aimed at identifying predictors of job satisfaction, and many studies have already confirmed that distress and stress are correlated with job satisfaction (Admiraal & Røberg, 2023; Anees et al., 2021; Pinto et al., 2024). For example, feelings of distress showed a stronger negative correlation with teachers' satisfaction with their school and career than other job demands such as high workload and additional tasks (Admiraal & Røberg, 2023).

Thus, because a wide range of brain regions are related to both stress and cognitive and social performance, it is possible that they mediate the relationship between the two. However, no studies have explicitly examined this mediation effect. Furthermore, most previous brain studies have focused on people with illnesses or the elderly, so little is known about how changes in brain structure seen in healthy middle-aged people are related to psychological distress and job satisfaction. Therefore, this study is the first attempt to examine whether individual differences in brain structure in middle-aged male and female workers who consider themselves healthy mediate the relationship between psychological distress and job satisfaction.

2. Materials and methods

2.1. Participants

80 participants (59 men, 21 women) aged 26 to 67 years (mean = 47.02, standard deviation (SD) = 12.05) were recruited to the Institute of Science Tokyo from November to December 2024. The necessary number of participants was calculated using G*Power 3.1.9.7, assuming an effect size (correlation coefficient) of 0.3 equivalent to "medium" according to the Cohen (1988) criteria, an alpha error probability of 0.05, and a power (1–β error probability) of 0.8. Respondents were randomly recruited from the BHQ Consortium, a study group aiming to utilize brain information in industry (BHQ Inc, 2025). According to the self-report, no subjects recruited had records of neurological, psychiatric, or other medical conditions that could affect the central nervous system. Brain images were taken using MRI, and the participants then answered a questionnaire. This study was approved by the Ethics Committee of Institute of Science Tokyo (Approval Number 2022130) and was conducted following the institutes' guidelines and regulations. All methods were carried out according to the relevant guidelines, regulations, and principles of the Declaration of Helsinki. All participants provided written informed consent before participation, and their anonymity was maintained.

2.2. Scale

2.2.1. Psychological scale

In addition to distress and job satisfaction, which are expected to have a direct relationship with the brain, we adopted 12 variables that have been shown to be related to distress and job satisfaction (Bakker et al., 2023; Kato et al., 2021; Mazzetti et al., 2023) based on a review of previous studies based on the Job demand-resource model (Demerouti et al., 2001). These are four variables of effort-reward imbalance, overcommitment, work-to-family negative spillover, and family-to-work negative spillover as demands, four variables of role clarity, psychological empowerment, psychological safety, and social capital as resources, and four variables of work engagement, performance, intention to quit, and subjective wellbeing as outcomes. Unless otherwise noted, responses were given on a five-point scale ranging from strongly disagree to strongly agree. Each response was assigned a score of 1 to 5 when scoring, and the arithmetic mean was used as the value of the variable.

2.2.2. Mediator

2.2.2.1. Distress. Distress was measured with the Japanese version (Furukawa et al., 2008) of the Kessler 6-item psychological distress scale (K6) (Kessler et al., 2002). The K6 asks respondents how often they have experienced symptoms of psychological distress (e.g. feeling so sad that nothing can cheer you up) in the past 30 days. Responses are recorded using a 5-point Likert scale and are typically rated as a sum score ranging from 0 to 24. In this study, we used the arithmetic mean of the 6 items, ranging from 0 to 4, to facilitate comparison with other scales. The Cronbach alpha reliability coefficient was 0.895.

2.2.2.2. Job satisfaction. We used the Japanese version (Hara & Fujimoto, 2020) of three items developed by Cammann et al. (1979) (e.g., All in all, I am satisfied with my job.) The Cronbach alpha reliability coefficient was 0.870.

2.2.3. Demand

2.2.3.1. Effort-reward imbalance. Effort (three items including "I have constant time pressure due to a heavy work load") and reward (seven items including "I receive the respect I deserve from my superior or a respective relevant person") were adopted from a shortened version (Siegrist et al., 2009) of the effort–reward imbalance scale developed by Siegrist et al. (2004). The Japanese translation was from Tsutsumi et al. (2001). The Cronbach alpha reliability coefficients were 0.815 for effort and 0.795 for reward. Following the developer's guidelines, we used the value obtained by dividing effort by reward as the effort-reward imbalance in the analysis.

2.2.3.2. Overcommitment. Overcommitment was measured using the Japanese translation of the overcommitment scale (6 items including "I get easily overwhelmed by time pressures at work") developed by Siegrist et al. (2004). The Japanese translation was taken from Tsutsumi et al. (2001). The reliability coefficient of Cronbach's alpha was 0.750.

2.2.3.3. Work-family negative spillover and family-work negative spillover. Two variables were adopted from the Japanese version (Shimada et al., 2018) of the Survey Work–Home Interaction (Geurts et al., 2005): work-family negative spillover (e.g., You are irritable at home because your work is demanding?) consisting of eight items and family-work negative spillover (e.g., The situation at home makes you so irritable that you take your frustrations out on your colleagues?) consisting of four items. The reliability coefficients of Cronbach's alpha were 0.921 and 0.759, respectively.

2.2.3.4. Role clarity. We used the role ambiguity scale (6 items) developed by Rizzo et al. (1970). For the Japanese translation, we used Suzuki (2015) for "Explanation is clear of what has to be done" and Hotta et al. (2022) for the remaining 5 items. The reliability coefficient of Cronbach's alpha was 0.868.

2.2.4. Psychological empowerment

We used the Japanese version of the Psychological Empowerment Scale (Watanabe & Kanai-Pak, 2019), which is composed of 12 items developed by Spreitzer (1995). This scale consists of four subdimensions: meaning (3 items including "The work 1 do is very important to me", competence (3 items including "I am confident about my ability to do my job"), self-determination (3 items including "I have significant autonomy in determining how 1 do my job"), and impact (3 items including "My impact on what happens in my department is large"). In this study, we used the arithmetic mean of the 15 items as the overall score, following the developer's guidelines. The reliability coefficient of Cronbach's alpha was 0.917.

2.2.5. Psychological safety

We used the Japanese version (Sasaki et al., 2022) of the scale developed by O'Donovan et al. (2020). This scale consists of three subscales: team leader (9 items including "If I had a question or was unsure of something in relation to my role at work, I could ask my team leader"), peers (7 items including "If I had a question or was unsure of something in relation to my role at work, I could ask my peers"), and team as a whole (3 items including "It is easy to ask other members of this team for help"). In this study, we used the arithmetic mean of the 19 items as the overall score, following the developer's guidelines. The reliability coefficient of Cronbach's alpha was 0.917.

2.2.6. Social capital

We used the Japanese version (Takao, 2016) of the eight-item scale developed by Kouvonen et al. (2006) (e.g., Our supervisor treats us with kindness and consideration.) The reliability coefficient of Cronbach's alpha was 0.922.

2.2.7. Outcome

2.2.7.1. Work engagement. We used the ultra-short measure for work engagement, consisting of three items (e.g., I have felt bursting with energy while working) developed by Schaufeli et al. (2017). The Japanese translation was from Shimazu et al. (2008). The reliability coefficient of Cronbach's alpha was 0.881.

2.2.7.2. Work performance. The evaluation was based on responses to the Japanese version (Kawakami et al., 2020) of the item developed by Kessler et al. (2003), "Using the same 0-to-10 scale, how would you rate your overall job performance on the days you worked during the past 4 weeks (28 days)?"

2.2.7.3. Intention to quit. We used the Japanese version (Hara & Fujimoto, 2020) of three items from Colarelli (1984) (e.g., I frequently think of quitting my job). The reliability coefficient of Cronbach's alpha was 0.882.

2.2.7.4. Satisfaction with life. We used the Japanese version (Sumino, 1994) of a scale consisting of five items (e.g., In most ways my life is close to my ideal.) developed by Diener et al. (1985). The reliability coefficient of Cronbach's alpha was 0.859.

2.2.8. MRI data acquisition

In this study, we focused on brain gray matter volume (GMV) represented by Gray Matter Brain Healthcare Quotient (GM-BHQ). GM-BHQ has been approved as an international standard by the standardization organization International Telecommunication Union Telecommunication Standardization Sector (ITU-T) as a "numerical index representing the physical characteristics of the brain that indicate health-related conditions" (approval number: ITU-TH.861.0). For the calculation of GM-BHQ, we adopted the same methodology as in our previous study (Kokubun et al., 2023; Nemoto et al., 2017).

All magnetic resonance imaging (MRI) data were obtained using a 3-T Siemens scanner (MAGNETOM Prisma, Siemens, Munich, Germany) which has a 32-channel head array coil and a three-dimensional (3D) T1-weighted magnetization-prepared and rapid-acquisition gradient echo pulse sequence. The parameters include repetition time (TR), 1900 ms; echo time (TE), 2.52 ms; inversion time (TI), 900 ms; flip angle, 9°; matrix size, 256 × 256; field of view (FOV), 256 mm; and slice thickness, 1 mm. DTI data were collected by spin-echo echo-planar imaging (SE-EPI) using generalized auto-calibrating partially parallel acquisitions (GRAPPA). The image slices were parallel to the orbitomeatal (OM) line with the parameters: TR = 14,100 ms; TE = 81 ms; flip angle = 90°; matrix size = 114 × 114; FOV = 224 mm; slice thickness = 2 mm. The baseline image (b = 0 s/mm^2) and 30 different diffusion directions were obtained with a b-value of 1000 s / mm^2.

2.3. MRI data analysis

T1-weighted images were pre-processed and analyzed using Statistical Parametric Mapping 12 (SPM12; Wellcome Trust Center for Neuroimaging, London, United Kingdom) running on MATLAB R2015b (Mathworks Inc., Sherborn, MA, United States). Each MPRAGE image was divided into gray matter (GM), white matter (WM), and cerebrospinal fluid (CSF) images. The segmented GM images were spatially normalized using a diffeomorphic anatomical registration through an exponentiated Lie algebra (DARTEL) algorithm (Ashburner, 2007). A modulation step was also incorporated into the pre-processing model to reflect the regional volume and preserve the total GM volume before the warp. As a final preprocessing step, all normalized, segmented, and modulated images were smoothed with an 8 mm full width at half-maximum (FWHM) Gaussian kernel. Intracranial volume (ICV) was calculated by summing the GM, WM, and CSF images for each subject. Proportional GM images were generated by dividing the smoothed GM image by ICV to control for differences in whole-brain volume between participants. These proportional GM images were used to generate the mean and standard deviation (SD) images of all participants. Next, individual GM quotient images were calculated using the following formula: 100 + 15 × (individual proportional GM–mean)/SD. Next, automatic anatomical labeling (AAL) atlas73 was used to extract regional GM quotients to create participant-specific GM-BHQs. For more details, see Nemoto et al. (2017) and Kokubun et al. (2023).

2.4. Analysis

First, we estimated correlation coefficients and partial correlation coefficients controlling for demographic variables (sex, age, BMI, education, and occupation) for the relationship between the subscales and total scale of GMV, psychological distress, and job satisfaction. Among the demographic variables, sex, age, and BMI are related to brain structure and therefore have been significantly correlated with GM-BHQ in previous studies (Kokubun et al., 2021; Kokubun & Yamakawa, 2019). On the other hand, education and occupation have been shown to be related to psychological distress and job satisfaction in previous studies (Brännlund & Hammarström, 2014; Montuori et al., 2022). Therefore, these demographic variables were included as covariates to increase the generalizability of the results by removing the influence of these background factors. For psychological distress and job satisfaction, we analyzed correlations with other psychological measures to aid in the interpretation of these measures. Next, we tested the mediation effect of subscales and total scale of GMV on the relationship between psychological distress and job satisfaction using path analysis. The criterion for

significance was set at 5 % for a two-sided test. Correlations between brain and psychological measures, and mediation effects of the brain, were examined using multiple comparisons using the Benjamini & Hochberg (BH) method. All statistical analyses have been performed using IBM SPSS Statistics/AMOS Version 26 (IBM Corp., Armonk, NY, USA) and all scatter plots were generated using GraphPad Prism (GraphPad software Inc., California, USA).

Table 1
Descriptive statistics.

	Mean	SD
Brain gray matter volume		
Frontal lobe	101.55	9.40
Temporal lobe	101.41	8.62
Parietal lobe	100.65	7.81
Whole brain	99.79	8.52
Mediator		
Distress	5.84	5.95
Job Satisfaction	3.84	0.92
Demand		
Effort-reward imbalance	3.00	1.08
Overcommitment	2.68	0.81
Work-to-family negative spillover	2.20	0.94
Family-to-work negative spillover	1.52	0.61
Resource		
Role clarity	3.75	0.74
Psychological empowerment	3.70	0.76
Psychological safety	4.15	0.51
Workplace social capital	3.90	0.77
Outcome		
Work engagement	4.03	1.08
Performance	7.40	1.38
Intention to quit	1.99	1.04
Subjective wellbeing	3.18	0.82
Demographic		
Age	47.03	12.05
BMI	23.64	3.74
Years of education	17.05	2.07

	N	%
Sex		
Male	59	73.8
Female	21	26.3
Occupation		
Managerial	20	25.0
Professional/technical	37	46.3
Administrative	11	13.8
Service	7	8.8
Sales	3	3.8
Security	1	1.3
Construction/mining	1	1.3
Occupation		
<1 year	2	2.3
1–3 years	5	5.7
3–5 years	14	16.1
5–10 years	16	18.4
10–20 years	13	14.9
More than 20 years	30	34.5

BMI = body mass index computed from height and weight.

3. Results

Table 1 shows descriptive statistics. The proportion of the sample was 73.8 % male and 26.3 % female. The number of workers in Japan in 2024 was 36.99 million males (54.5 %) and 30.82 million females (45.5 %) (Ministry of Internal Affairs and Communications, 2024), so the sample in this study is biased toward men. In addition, 25 % of the sample were managers. Since the proportion of managers in Japan in 2021 is estimated to be 11.5 % (Selection & Variation, 2024), the sample in this study is relatively dominated by managers. In terms of length of service, the higher proportion was "More than 20 years" at 34.5 %, and compared to the average length of service in Japan in 2023 of 12.7 years (National Tax Agency, 2023), the sample in this study is biased toward long-term employees. These suggest that there is a high possibility that the sample was biased because it was collected through the BHQ Consortium, a gathering of businesspersons interested in the brain. Thus, the set of results presented below, although controlled for demographic variables, should be approached with caution.

Table 2 shows correlation coefficients between the subscales and total scale of GMV and psychological scales. Below the diagonal are ordinary correlation coefficients, while above are partial correlation coefficients controlling for demographic variables. Spearman's rho was used because some psychological scales did not follow a normal distribution. Ordinary correlation coefficients did not show a significant correlation between the subscales and total scale of GMV for either distress or job satisfaction. However, this is an expected result given previous studies showing that these variables depend on demographic variables (Brännlund & Hammarström, 2014; Kokubun et al., 2021; Kokubun & Yamakawa, 2019; Montuori et al., 2022). In this study, all brain variables showed correlations of 0.3 or more with sex, age, and BMI, which corresponds to the "medium" level (Cohen, 1988). On the other hand, there was no significant correlation between brain variables and education, and while some correlations between brain variables and occupation dummies (managerial, professional/technical, administrative) were significant, most were below the medium-level effect size. Furthermore, these coefficients, although significant, are difficult to interpret. For example, the correlation between the whole brain and the managerial dummy ($r = -0.318$, $p = 0.004$) is negative, which contradicts previous arguments that more knowledge work slows brain ageing (e.g., Lövdén et al., 2017). This is because both the whole brain ($r = -0.777$, $p = 0.000$) and the managerial dummy ($r = 0.290$, $p = 0.009$) are correlated with age, which is likely the reason for the spurious correlation between the two. Stress and job satisfaction also showed two pairwise small but significant correlations with the demographic variables: stress and age ($r = -0.237$, $p = 0.034$) and job satisfaction and administrative dummy ($r = -0.238$, p = 0.034).

On the other hand, the partial correlation coefficients showed a significant negative correlation with distress in the frontal lobe ($r = -0.286$, $p = 0.014$), temporal lobe ($r = -0.259$, $p = 0.027$), parietal lobe ($r = -0.340$, $p = 0.003$), and whole brain ($r = -0.298$, p = 0.01). Also, a significant positive correlation with job satisfaction in the frontal lobe ($r = 0.311$, $p = 0.007$), temporal lobe ($r = 0.315$, p = 0.007), parietal lobe ($r = 0.318$, $p = 0.006$), and whole brain ($r = 0.265$, $p = 0.023$). All of these significances survived multiple comparisons.

Table 3 shows the correlations between psychological scales. Below the diagonal are the usual correlation coefficients, and above the diagonal are the partial correlation coefficients controlled for demographic variables. For ease of interpretation and in terms of multiple comparisons, only results with p-values below 0.001, the most conservative value, are included in the discriptions here. First, distress was significantly correlated with effort-reward imbalance ($r = 0.427$, p = 0.000), overcommitment ($r = 0.451$, p = 0.000), and family-to-work negative spillover ($r = 0.486$, p = 0.000). On the other hand, job satisfaction was significantly correlated with role clarity ($r = 0.539$, p = 0.000), psychological empowerment ($r = 0.636$, p = 0.000), psychological safety ($r = 0.568$, p = 0.000), social capital ($r = 0.420$, p = 0.000), work

Table 2
Correlation between subscale and total scale of GMV and psychological scales.

		1	2	3	4	5	6	7	8	9	10	11	12
1	Frontal lobe		0.625***	0.590***	0.797***	−0.286*	0.311**						
2	Temporal lobe	0.858***		0.643***	0.749***	−0.259*	0.315**						
3	Parietal lobe	0.860***	0.879***		0.763***	−0.340**	0.318**						
4	Whole brain	0.925***	0.916***	0.930***		−0.298*	0.265*						
5	Distress	0.057	0.069	0.039	0.089		−0.317**						
6	Job Satisfaction	0.166	0.192	0.184	0.143	−0.290**							
7	Sex	0.393***	0.370**	0.386***	0.451***	0.141	0.166						
8	Age	−0.713***	−0.732***	−0.762***	−0.777***	−0.237*	0.001	−0.188					
9	BMI	−0.598***	−0.558***	−0.566***	−0.589***	−0.151	−0.070	−0.491***	0.379**				
10	Education	0.152	0.092	0.156	0.122	0.037	−0.115	−0.197	−0.210	0.081			
11	Managerial	−0.205	−0.270*	−0.284*	−0.318**	0.008	−0.046	−0.213	0.290**	0.164	−0.150		
12	Professional/technical	−0.008	−0.030	0.024	−0.001	−0.155	0.123	−0.041	−0.097	0.074	0.308**	−0.536***	
13	Administrative	0.257*	0.227*	0.215	0.281*	0.120	−0.238*	0.339**	−0.123	−0.177	−0.074	−0.231*	−0.370**

Note: $n = 80$; *p < 0.05; **$p < 0.01$; ***$p < 0.001$. Below the diagonal are ordinary correlation coefficients, above the diagonal are partial correlation coefficients controlled for demographic variables including sex, age, BMI, education and occupation dummies (management, professional/technical, administrative, and others). Both are Spearman's rho.

Table 3
Correlations between psychological scales.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Distress		−0.317**	0.427***	0.451***	0.338**	0.486***	−0.159	−0.153	−0.249*	−0.379**	−0.178	−0.223	0.290*	−0.298*
2	Job satisfaction	−0.290**		−0.334**	−0.083	−0.203	−0.267*	0.539***	0.636***	0.568***	0.420***	0.750***	0.645***	−0.497***	0.382**
3	Effort-reward imbalance	0.381***	−0.328**		0.553***	0.592***	0.195	−0.262*	−0.173	−0.365**	−0.517***	−0.320**	−0.103	0.510***	−0.340**
4	Overcommitment	0.473***	−0.105	0.527***		0.680***	0.330*	0.017	0.080	−0.079	−0.134	−0.005	0.080	0.348**	−0.210
5	Work-to-family negative spillover	0.347**	−0.190	0.535***	0.660***		0.413***	−0.228	−0.044	−0.273*	−0.309	−0.175	−0.079	0.501***	−0.292*
6	Family-to-work negative spillover	0.488***	−0.240*	0.178	0.316**	0.434***		−0.224	−0.129	−0.306**	−0.236*	−0.259*	−0.167	0.261*	−0.304**
7	Role clarity	−0.190	0.567***	−0.228*	−0.031	−0.248*	−0.225*		0.540***	0.641***	0.464***	0.504***	0.567***	−0.314**	0.239*
8	Psychological empowerment	−0.182	0.635***	−0.147	0.04	−0.091	−0.150	0.586***		0.644***	0.458***	0.573***	0.571***	−0.305**	0.429***
9	Psychological safety	−0.211	0.609***	−0.372**	−0.109	−0.254*	−0.254*	0.639***	0.637***		0.711***	0.518***	0.493***	−0.454***	0.331**
10	Social capital	−0.329**	0.478***	−0.521***	−0.14	−0.280*	−0.218	0.446***	0.445***	0.724***		0.394**	0.320**	−0.390**	0.397**
11	Work engagement	−0.184	0.761***	−0.308**	−0.036	−0.186	−0.254*	0.516***	0.557***	0.535***	0.435***		0.577***	−0.359**	0.383**
12	Performance	−0.237*	0.654***	−0.085	0.044	−0.071	−0.152	0.555***	0.528***	0.472***	0.346**	0.597***		−0.288*	0.374**
13	Intention to quit	0.286*	−0.512***	0.449***	0.329**	0.470***	0.235*	−0.355**	−0.391***	−0.472***	−0.395***	−0.365**	−0.299**		−0.236*
14	Subjective wellbeing	−0.314**	0.441***	−0.333**	−0.224*	−0.309**	−0.335**	0.297**	0.468***	0.372**	0.457***	0.429***	0.395***	−0.272*	

Note: n = 80; *p < 0.05; **p < 0.01; ***p < 0.001.
Below the diagonal are ordinary correlation coefficients, above the diagonal are partial correlation coefficients controlled for demographic variables including sex, age, BMI, education and occupation dummies (managerial, professional/technical, administrative, and others). Both are Spearman's rho.

engagement ($r = 0.750$, p = 0.000), performance ($r = 0.645$, p = 0.000), and intention to quit ($r = -0.497$, p = 0.000). In other words, distress was significantly correlated with demand, and job satisfaction was significantly correlated with resource and outcome.

Table 4 shows the results of the analysis of the mediation effect by path analysis. In all cases, a significant direct effect was shown between distress and job satisfaction. In addition, in all cases, the subscales and total scale of GMV showed a significant indirect effect mediating distress and job satisfaction. All of these indirect effects survived multiple comparisons. Figs. 1, 2, and 3 show the mediation effects in scatter plots.

4. Discussion

Previous studies have shown that distress and stress can affect the brain and that this can lead to poorer task performance. However, few studies have examined these relationships in a unified manner or conducted on participants without medical conditions. The cross-sectional analysis of this study conducted on healthy middle-aged men and women indicates that the GMV of the frontal, temporal, and parietal lobes, as well as the whole brain, partially mediate the relationship between distress and job satisfaction. Distress is positively correlated with effort-reward imbalance, overcommitment, and family-to-work negative spillover, suggesting that it is likely to increase with high demand. On the other hand, job satisfaction is positively correlated with role clarity, psychological empowerment, psychological safety, and social capital, suggesting that it is likely to increase with high resources. In addition, job satisfaction is positively correlated with work engagement, performance, and negatively with intention to quit, suggesting that high job satisfaction is likely to improve workplace outcomes. Therefore, the results of this study suggest that high demands can increase distress, leading to atrophy of the brain, particularly the frontal, temporal, and parietal lobes, which in turn can reduce job satisfaction and decrease motivation and performance at work.

Previous studies have revealed that psychological distress and stress are related to job satisfaction (Admiraal & Røberg, 2023; Anees et al., 2021; Pinto et al., 2024). Job satisfaction is one of the most important indicators in the workplace, as it is related to work performance (Katebi et al., 2022; Riketta, 2008; Weiler, 2004) and turnover intentions (Anees et al., 2021; Hellman, 1997; Hua et al., 2023). On the other hand, although previous studies have confirmed that brain atrophy is related to stress and social performance in healthy individuals (Kokubun et al., 2018; Kokubun et al., 2023), the number of studies is small. However, symptoms accompanied by atrophy due to brain disease interestingly share some commonalities with these studies, and there is a greater accumulation of research.

For example, frontotemporal dementia (FTD) is a type of dementia that primarily affects the frontal and temporal lobes of the brain, which

Fig. 1. Scatter plot of distress and job satisfaction.
Δ: residuals controlled for demographic variables. The straight line is the regression line, and the dashed lines are the 95 % confidence intervals.

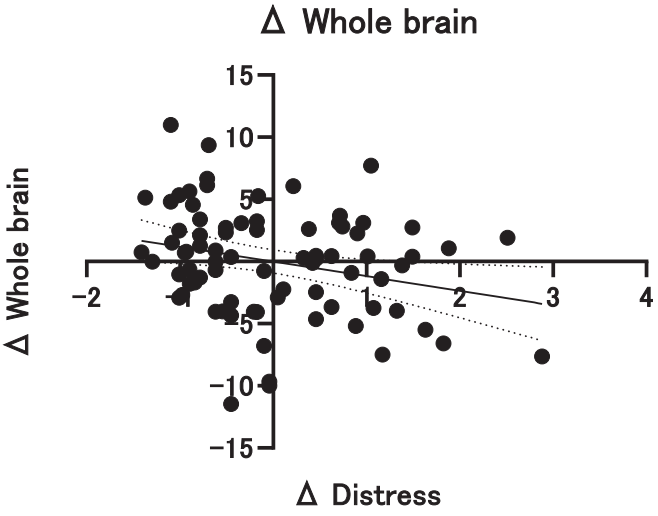

Fig. 2. Scatter plot of distress and whole brain.
Δ: residuals controlled for demographic variables. The straight line is the regression line, and the dashed lines are the 95 % confidence intervals.

Table 4
Results of mediation effect analysis using path analysis.

Relationship	Direct				Indirect				Conclusion
	Effect	Confidence Interval		P-value	Effect	Confidence Interval		P-value	
		Lower Bound	Upper Bound			Lower Bound	Upper Bound		
Distress - > Frontal lobe - > Job Satisfaction	−0.294 (0.111)	−0.513	−0.082	0.006**	−0.032 (0.020)	−0.082	−0.001	0.036*	Partial Mediation†
Distress - > Temporal lobe - > Job Satisfaction	−0.294 (0.111)	−0.515	−0.082	0.006**	−0.035 (0.023)	−0.097	−0.003	0.023*	Partial Mediation†
Distress - > Parietal lobe - > Job Satisfaction	−0.292 (0.113)	−0.514	−0.078	0.007**	−0.034 (0.020)	−0.088	−0.004	0.021*	Partial Mediation†
Distress - > Whole brain - > Job Satisfaction	−0.301 (0.111)	−0.516	−0.087	0.006**	−0.026 (0.018)	−0.076	−0.002	0.030*	Partial Mediation†

Note: n = 80; *p < 0.05; **p < 0.01; ***p < 0.001. The numbers in parentheses in the table are standard errors. Mediators (frontal lobe, temporal lobe, parietal lobe, and whole brain) are controlled for sex, age, and BMI. Job Satisfaction is controlled for education and occupation dummies (managerial, professional/technical, administrative, and others). †Benjamini & Hochberg (BH) multiple comparisons showed significant differences ($p < 0.05$).

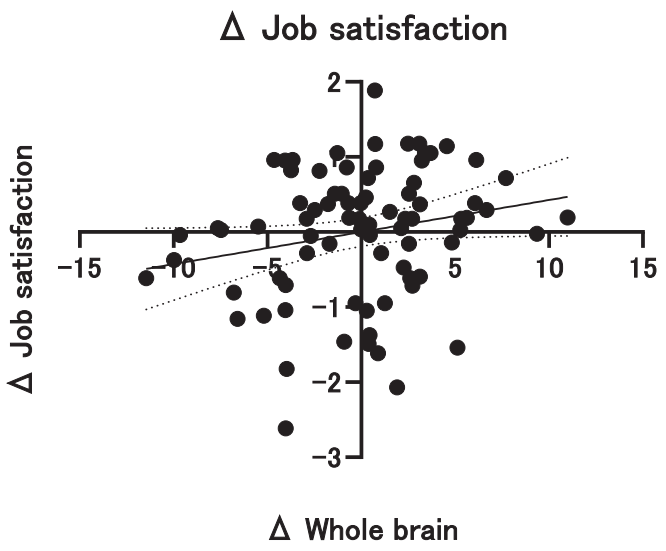

Fig. 3. Scatter plot of whole brain and job satisfaction.
Δ: residuals controlled for demographic variables. The straight line is the regression line, and the dashed lines are the 95 % confidence intervals.

control personality, behavior, language, and speech, and is notoriously difficult to notice. The most common type of FTD, behavioral variant frontotemporal dementia (bvFTD), also known as Pick's disease or frontal lobe dementia, primarily affects the areas of the brain that control social behavior (Khan & De Jesus, 2023). FTD occurs when abnormal proteins build up in the brain, clump together, and damage cells (National Institute of Aging, 2021). FTD is most commonly diagnosed in people between the ages of 45 and 65, but younger and older people can also be affected. It also affects both men and women equally (Dementia UK, 2025).

Symptoms of FTD progress gradually and worsen over time. Unlike many other types of dementia, where memory and concentration are often the first to be affected, early signs of FTD are changes in personality, behavior, and problem-solving abilities (Dementia UK, 2025). For example, symptoms of bvFTD include reduced empathy and ability to understand other people's opinions, difficulty concentrating on tasks and being easily distracted, difficulty planning, organizing, and making decisions, problems managing finances and dealing with work, and lack of insight and awareness of change (Dementia UK, 2025; National Institute of Aging, 2021). However, there is often a significant delay in identifying FTD due to a lack of awareness of the early symptoms in many people, mistaking these signs for other symptoms such as depression, stress, relationship problems, and work-related problems, and the misconception that dementia only occurs in older people (Dementia UK, 2025).

Evidence indicates that FTD is often due to stress. Johansson et al. followed 1462 Swedish women in a long-term longitudinal design over a 35-year period. After controlling for many potential confounding variables, including demographic, behavioral, and other known risk factors such as waist-hip ratio, subjects who reported stress were at higher risk for Alzheimer's disease (AD) compared to those who did not (Johansson et al., 2010). The researchers concluded that there is an association between psychological stress in midlife and the later development of dementia, especially AD. Furthermore, a subsequent study showed that women who reported frequent or constant stress in the 5 years prior to testing were more likely to have moderate to severe temporal lobe atrophy compared to women who did not report stress. The researchers concluded that prolonged psychological stress in midlife increases the risk of brain atrophy in later life (Johansson et al., 2012).

In a retrospective analysis of the care database of 181,093 veterans aged 55 years or older, Yaffe et al. found that the cumulative 7-year dementia incidence rate was 10.6 % in those with a history of Post Traumatic Stress Disorder (PTSD), compared with 6.6 % in those without PTSD. Interestingly, PTSD was associated with all types of dementia, with the strongest association being with FTD. The authors concluded that people diagnosed with PTSD had almost twice the risk of developing dementia compared with those without a diagnosis of PTSD (Yaffe et al., 2010).

Dementia-related atrophy of the temporal, parietal, and frontal lobes worsens as the disease progresses (Braskie et al., 2012; Greenberg et al., 2014; Whitwell et al., 2008). Chronic stress and gray matter atrophy in these brain regions are often associated with memory decline (Zhao et al., 2024) as well as burnout-like symptoms such as reduced motivation (Arnsten & Shanafelt, 2021). A previous study analyzed the correlation between normalized whole-brain, frontal, and temporal GMV and Trail Making Test (TMT) scores in 95 patients with chronic kidney disease (CKD) and showed that frontotemporal gray matter atrophy may contribute to executive dysfunction (Tsuruya et al., 2015). Similarly, a study of 103 patients diagnosed with bvFTD showed that executive function performance was primarily related to prefrontal GMV, and that anterior temporal lobe atrophy was involved in theory of mind (ToM) deficits (Weise et al., 2024).

Based on the results of this study alone, it is unreasonable to claim that psychological stress leads to FTD or related disorders. FTD is considered a rare dementia, accounting for only approximately 15 % of all diagnosed dementias (Piguet & Kumfor, 2020). However, at least, the results of this study indicate that even if a person have not been diagnosed with FTD, workplace stress may cause brain atrophy in the frontal, temporal and parietal lobes, leading to reduced motivation and performance at work. This indicates that more middle-aged men and women who are aware of their health may be suffering from reduced performance due to brain disorders caused by stress than previously believed. Similar to COR theory, this could mean that the demands of our jobs can drain brain resources, causing brain atrophy and reducing performance and job satisfaction (de Andrade et al., 2016; Muraven & Baumeister, 2000).

The relationship with other psychological variables is mainly that distress is related to demand, and job satisfaction is related to resources and outcomes. Looking back at how to improve employee outcomes as a major theme in organizational psychology, it is easy to understand the model shown in this study, in which demand is the starting point, job satisfaction is the end point, and the brain mediates the two. However, this study is a cross-sectional analysis, and it is possible that the causal relationship is reversed. In other words, a decrease in job satisfaction may lead to brain atrophy and increased mental distress. As previous studies have shown, not obtaining expected levels of outcomes or resources may reduce job satisfaction along with a decrease in self-efficacy (Cayupe et al., 2023; Ortan et al., 2021), and mental distress may reduce the ability to cope with work and make workers feel that demand is greater (Abadi et al., 2021; Andlib et al., 2022). Therefore, the causal relationship of the model presented in this study needs to be verified in future longitudinal studies.

The results of this study show the importance of regularly checking employees' mental health and taking measures. Although the number of organizations taking such measures is on the rise, surveys that focus on employee motivation are likely to allow interpretations that are convenient for management, which can ultimately lead to exhaustion of employees and the risk of leading to the exploitation of their passion (Kokubun, 2024). Rather than measuring their motivation from a short-term perspective, it is necessary to focus on the living organism that is the source of their motivation from a long-term perspective. To this end, it may be useful to use the condition of the brain as a biomarker. Although measuring the condition of the brain with MRI is expensive and troublesome, it is possible to identify risk factors that may affect the brain from surveys using the group of variables adopted in this study, predict the possible consequences of removing or not removing those factors, and take measures.

Therefore, the results of this study may be useful in forming a new

mental health support system in the workplace. For managers, even if the stress that employees are experiencing is serious, it may sometimes be difficult to recognize its importance. It would be better if they only forced employees to do something temporarily because of an approaching deadline or because they do not want to lose the trust of their clients, but in workplaces where they have become dependent on employees and have a tendency to think, "They did it before, so they will do it again," and this has become a state of affairs, it may become the moral code of the workplace and make it difficult for managers to notice. However, if it is understood that such errors in judgment affect the human brain, a living organism, managers should pay more serious attention to the way employees work. The formation of a new mental health support system based on the brain, which involves a change in the way we view work, may bring benefits to both labor and management, especially if we take a long-term perspective.

This study is the first to show that whole and regional brain volume measured by GMV partially mediates between distress, which is related to demand, and job satisfaction, which is related to resources and outcomes, in middle-aged men and women who consider themselves healthy. In the future, the results of this study may be verified or utilized in various ways to eliminate obstacles to workers' brain health and predict performance, thereby contributing to the development of well-being for both workers and management.

4.1. Limitation

This study was conducted using am analysis with a small sample size data. The number of participants, 80, is appropriate for correlation coefficients assuming a medium effect size, but is small for mediation analysis involving complex processes (Wolf et al., 2013). Therefore, it is possible that the power and reliability of the current research were less sufficient than those that could have been obtained with a larger sample size. In addition, by limiting participants to Japanese people, it is possible that the unique work perspectives and biological characteristics of Japanese people may have influenced the results. Sample bias and deviations from the average of Japanese people also mean that these results should be interpreted with caution. Furthermore, because we used cross-sectional data, we were unable to confirm changes in the relationships between distress, brain volume, and job satisfaction over time. In addition, observing subtle changes in addition to brain structure requires the use of more advanced neuroimaging analytic methods (e.g., structural-functional coupling of brain networks; Suo et al., 2025). Future studies should verify the results of this study through longitudinal studies with a large unbiased samples from a variety of nationalities using various modern analytical methods.

5. Conclusion

As the global population ages and labor shortages continue, people are becoming more interested in the brain. Previous studies have shown that distress and stress can affect the brain, and that such effects can lead to poorer task performance. The results of the cross-sectional analysis of this study, which was conducted on healthy middle-aged men and women, show that the GMV of the frontal, temporal, and parietal lobes, as well as the whole brain, partially mediate the relationship between distress and job satisfaction. In the future, the results of this study may be verified or utilized in various ways to remove obstacles to workers' brain health and promote their performance, thereby contributing to the development of wellbeing for both labor and management.

CRediT authorship contribution statement

Keisuke Kokubun: Writing – original draft, Formal analysis, Conceptualization. **Kiyotaka Nemoto:** Writing – review & editing, Resources, Data curation. **Yoshinori Yamakawa:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Consent for publication

All participants gave consent for the publication of the results of this study.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Institute of Science Tokyo (Approval Number 2022130) and was conducted following the institute's guidelines and regulations. All participants provided written informed consent before participation, and their anonymity was maintained.

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Declaration of competing interest

The authors have declared that no competing interests exist.

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Data availability

The datasets generated during the current study are not publicly available but are available from the corresponding author upon reasonable request.

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