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Brain Fog Scale (BFS): Scale development and validation

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ABSTRACT

Recently, we have witnessed a rapid increase in the number of research studies in the area of brain fog, predominantly due to the fact that it is reported to be a frequent long COVID condition. However, the construct of brain fog remains ill-defined and a common method of assessment of the condition is lacking. Therefore, the main aim of the current study was to develop and validate a self-report Brain Fog Scale (BFS) for use in clinical and research settings. Participants were 1452 ($n = 996$, 68.6 % female) Polish university students. The data were collected anonymously through self-completion questionnaires. Results indicate that the 23-item BFS has good psychometric properties. Based on principal component analysis (PCA) and confirmatory factor analysis (CFA) results, the scale is best captured by a three-factor solution, with six items loading on the mental fatigue factor, nine items loading on the impaired cognitive acuity factor, and eight items loading on the confusion factor. We found that individuals who tested positive for COVID-19 had significantly higher mental fatigue, impaired cognitive acuity, and confusion scores than matched controls who never tested positive for COVID-19.

1. Introduction

The term "brain fog'" is frequently used anecdotally, without a uniform, widely accepted definition of the disorder (Ocon, 2013). The sensation of "fogginess" or "like being in a cloud" is commonly encountered in clinical practice, but it is not well explored in the literature (Lucius, 2021). In general, the phenomenon of brain fog is understood primarily as a cognitive impairment, with characteristic symptoms including problems with concentration and attention, confusion, forgetfulness, difficulty understanding what others are saying, reduced mental acuity, and mental fatigue (Ocon, 2013; Ross et al., 2013). These symptoms can be triggered by, among others, sleep disturbance, strenuous physical activity, poor nutrition, medication, or drugs (Kverno, 2021; Ocon, 2013; Ross et al., 2013; Ziauddeen et al., 2021). In addition, brain fog, understood as deficiencies in cognitive functioning, can be experienced by individuals with chronic fatigue syndrome (CFS). Those patients demonstrated reduced performance on neurocognitive tests and increased reaction time while completing tasks (Christodoulou et al., 1998; Ocon, 2013).

Brain fog has been reported as a common post-COVID complication, also referred to as "long COVID", even among patients who did not require hospitalisation (Krishnan et al., 2022). In an analysis of data from 2-year retrospective cohort studies involving 1,284,437 patients, Taquet et al. (2022) demonstrated that the risk of brain fog (defined as a cognitive deficit) among COVID-19 patients, compared with matched controls, was still increased at the end of the 2-year follow-up period. In a systematic review of 13 studies, Butardo et al. (2022) established that most frequently found cognitive deficits in COVID-19 patients were problems with memory, attention, and executive function. In three out of four studies comparing COVID-19 patients with healthy controls, cognitive impairment was only manifested among COVID-19 patients. Interestingly, the presence of cognitive dysfunction was not dependent on illness severity. The causal pathways through which COVID-19 infection may lead to brain fog remain unclear, but may involve

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neuroinflammation (Theoharides et al., 2021). The post-COVID experience of brain fog was also reported to have a profound psychosocial impact (Callan et al., 2022). However, the lack of a common definition and measurement method of the impairment means that studies conducted to date are not directly comparable.

Although research interest surrounding brain fog, especially in relation to COVID-19, has substantially increased over the last few years, reliable and efficient assessment of the disorder is yet to be developed. In considering the evidence indicating how common brain fogginess appears to be among COVID-19 survivors and the long-term debilitating effect it may have on people's lifestyle, there is a need for a reliable assessment of the condition that would render itself to wide and remote application in both research studies and clinical practice.

1.1. The current study

Despite the importance of the construct of brain fog, its nature, aetiology, and frequency are poorly understood. Contributing to this is the lack of a uniform definition as well as a validated measure of brain fog. Therefore, the first aim of the proposed study was to develop the Brain Fog Scale (BFS) – a self-report scale designed to assess a cognitive dysfunction characterised by problems with concentration and remembering, confusion, forgetting words, difficulty understanding what others are saying, and mental fatigue (Ross et al., 2013). The second aim was to examine the psychometric properties of the BFS. The BFS factor structure was assessed using a principal component analysis (PCA) and confirmatory factor analysis (CFA). The third aim was to investigate whether individuals who acquired COVID-19 infection (treatment group) have elevated levels of brain fog, compared with those who never tested positive for COVID-19 (comparison group). In order to reduce treatment selection bias, we performed a fuzzy matching procedure on demographic factors and risk factors for a viral infection. We predicted that participants who tested positive for COVID-19 (COVID+) would have significantly more brain fog symptoms than matched controls who never tested positive for COVID-19 (COVID-).

2. Method

2.1. Participants and data collection

Study participants were university students from a large Polish university with six campuses located in different regions of the country. The study was hosted in Qualtrics and administered via SONA, which is an online platform used to recruit students enrolled in various courses. Participants who completed the anonymous online survey received SONA credits, which enable students to use SONA for their own studies. Informed consent was obtained from each participant. Ethical clearance for the study was granted by the university ethics committee.

In total, 1605 students accessed our online survey link and 1509 consented to participate in the study, giving a 94 % response rate. Of the individuals who consented to participate, 1452 ($n = 996$, 68.6 % female) returned satisfactory data (defined as full response on the Brain Fog Scale). Therefore, the total completion rate was 90.5 %. Most data ($n = 1162$, 85.7 % female) were collected during the COVID-19 pandemic (October – December 2021). To remedy the gender imbalance in the original database, we collected additional data among men ($n = 290$) between June–July 2023. These will be referred to as the original and additional samples respectively. Age ranged from 18 to 58 years ($M = 25.93$, $SD = 7.61$, Median = 23). As for the level of study, 242 (16.7 %) participants were first year undergraduate students, 134 (9.2 %) were second year undergraduate students, 156 (10.7 %) were third year undergraduate students, 446 (30.7 %) were first year Master's students, 431 (29.7 %) were second year Master's students, and 30 (2.1 %) were postgraduate taught or postgraduate research students. Thirteen ($n = 13$, 0.9 %) students did not indicate their level of study. Most respondents ($n = 1327$, 91.4 %) were psychology students. The vast majority of participants were Caucasian ($n = 1440$, 99.2 %) and born in Poland ($n = 1434$, 98.8 %), which reflects the composition of the Polish society.

2.2. Scale development procedures and other instruments

2.2.1. Brain Fog Scale (BFS)

Brain Fog Scale (BFS) was developed to assess the construct of brain fog. Item generation for the BFS relied on theoretical considerations, the list of descriptors of the phenomenon generated by Ross et al. (2013), as well as discussions with a panel of experts (psychologists and medical doctors). First, we coined an operational definition of brain fog: *a cognitive dysfunction characterised by problems with concentration and memory, inattention, confusion, difficulty understanding spoken and written language, reduced mental acuity, and mental fatigue*. Second, based on the above definition and Ross et al.'s (2013) list of descriptors, we assembled 30 items reflecting the symptoms of brain fog. The initial item pool was sent to 10 experts who were asked to: (1) assess whether each item taps into the phenomenon we intended to measure, (2) evaluate clarity and conciseness of scale items, and (3) advise us on which items should and should not be included in the final version of the scale. This content validity procedure resulted in 23 items. For each item, respondents are asked to indicate on a 5-point Likert scale (0 = "never", 1 = "rarely", 2 = "occasionally", 3 = "a lot of the time", 4 = "nearly all the time") how often they have experienced each symptom during the last two weeks. Total scale scores range from 0 to 92, with higher scores indicating increased levels of brain fog.

2.2.2. Healthy and Unhealthy Eating Behavior Scale

Healthy and Unhealthy Eating Behavior Scale (HUEBS; Guertin et al., 2020) was used to assess the consumption of healthy and unhealthy foods. The scale consists of two subscales: healthy eating (11 items; e.g., "I eat fruits") and unhealthy eating (11 items; e.g., "I use white sugar or artificial sweeteners"). Respondents are asked to indicate the extent to which they generally consume the different food items on a 7-point Likert scale ranging from 1 = *never* to 7 = *always*. Scores for each subscale range from 11 to 77, with higher scores indicating higher consumption of healthy or unhealthy foods. In the current sample, Cronbach's alphas for healthy eating and unhealthy eating were 0.76 and 0.81 respectively.

2.2.3. Single-item Physical Activity Measure

Single-item Physical Activity Measure (Milton et al., 2011) was used to assess the level of physical activity over the past week ("In the past week, on how many days have you done a total of 30 minutes or more of physical activity, which was enough to raise your breathing rate. This may include sport, exercise, and brisk walking or cycling for recreation or to get to and from places, but should not include housework or physical activity that may be part of your job?"). Responses ranged from 0 to 7 days.

2.2.4. Perceived weight

Perceived weight was assessed using a single item: "How would you classify your weight?" with four response options: 1 = within the underweight range, 2 = within the healthy weight range, 3 = within the overweight range, 4 = within the obesity range. These answers were then collapsed into two categories: 'within the healthy range' (all participants who selected answer 2) and 'outside of the healthy range' (all participants who selected answers 1, 3, or 4).

2.2.5. Global health status

Global health status (Hays et al., 2015) was assessed with a single question: "In general, how would you rate your physical health?" with five response options: 1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent.

2.2.6. COVID-19 infection

COVID-19 infection was assessed with a single question: "Have you ever had a positive COVID-19 test result?". Responses were recorded as either 'yes' or 'no'.

2.3. Statistical analysis plan

Descriptive statistics were calculated using IBM SPSS Statistics, Version 28. To validate the BFS, the original sample was randomly split into two datasets with an equal proportion of males and females and a two-stage procedure was applied. First, a principal component analysis (PCA) with direct oblimin rotation method was used to extract factors of the BFS (dataset 1; $n = 581$). Second, in order to confirm the factor structure of the BFS identified by the PCA, a confirmatory factors analysis (CFA) with weighted least square estimator was applied using Mplus version 7.4 (Muthén & Muthén, 1998–2015). CFA dataset (dataset 2) contained participants from the original sample ($n = 581$)[1] and the additional sample ($n = 290$). To verify whether data is suitable for factor analysis, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and the Bartlett's Test of Sphericity were used. KMO values of 0.6 or above are considered acceptable. Statistically significant result of the Bartlett's Test of Sphericity indicates that the variables are correlated. Extracting factors was based on the Kaiser's criterion, i.e., factors were retained if the corresponding eigenvalue was greater than one (Kaiser, 1960). In CFA, the overall fit of the model was assessed via the $\chi 2$ statistic, the Comparative Fit Index (CFI; Bentler, 1990), and the Tucker Lewis Index (TLI; Tucker & Lewis, 1973). Fit is considered acceptable if the CFI and TLI values are above 0.90 (Van de Schoot et al., 2012). The Root Mean Square Error of Approximation (RMSEA; Steiger, 1990) with 90 % confidence interval is also presented, with values of about 0.08 or less indicating acceptable error of approximation in the population (Browne & Cudeck, 1993). To compare the configural and metric models of invariance across gender, we used criteria proposed by Chen (2007): less than 0.010 change in the CFI and TLI values and less than 0.015 change in the RMSEA value. Reliability was examined using Cronbach's alpha and coefficient omega (McDonald, 1999).

To assess whether individuals who acquired COVID-19 infection (treatment group; COVID+) had significantly different brain fog levels compared with those who did not contract the infection (comparison group; COVID-), we conducted independent samples *t*-tests using the original dataset. To reduce treatment selection bias, we performed fuzzy matching using propensity score calculated on a number of covariates, including demographic factors and risk factors for a viral infection (i.e., age, gender, perceived weight, physical activity, healthy eating, unhealthy eating, global health status) (see De Frel et al., 2020; Hamer et al., 2020; Zhou et al., 2020). The fuzzy matching technique attempts to assess the effect of treatment by accounting for covariates and hence correcting selection bias in making estimates (Rubin, 2006). We used the SPSS version 28 for macOS to perform 1:1 matching (FUZZ = 0.1).

3. Results

3.1. Descriptive statistics reported for all participants

Descriptive statistics for all continuous variables (BFS, healthy eating, unhealthy eating, and physical activity) are presented in Table 1. Descriptive statistics for ordinal and nominal data (global health status, perceived weight, and COVID-19 infection) are presented in Table 2.

Table 1
Descriptive statistics for the continuous variables.

Variables	*M* (95 % CI)	*SD*	*Median*	Observed Min.	Observed Max.
Brain Fog Scale	34.35 (33.46, 35.24)	17.04	33	0	91
Healthy eating	50.55 (50.11, 51.00)	8.56	50	24	77
Unhealthy eating	36.42 (35.93, 36.92)	9.48	36	11	76
Physical activity	2.98 (2.89, 3.08)	1.83	3	1	7

Table 2
Descriptive statistics for the ordinal and nominal variables.

Variable	Category	Frequency	Percent
Global health status	Poor	46	3.2
	Fair	228	15.7
	Good	486	33.5
	Very good	582	40.1
	Excellent	110	7.6
Perceived weight	Within the healthy range	1031	71.0
	Outside the healthy range	421	29.0
COVID-19 infection	Yes	406	28.0
	No	1046	72.0

3.2. Principal component analysis (PCA) and confirmatory factor analysis (CFA)

PCA with direct oblimin rotation method was used to extract factors from the BFS items (Kaiser-Meyer-Olkin [KMO] = 0.94; Bartlett's Test $\chi 2 = 8339.06$, df = 253, $p < .001$) using dataset 1 ($n = 581$). Three factors were extracted, with F1 explaining 47.76 % of variance (eigenvalue = 10.98), F2 explaining 6.67 % of variance (eigenvalue = 1.53), and F3 explaining 6.22 % of variance (eigenvalue = 1.43). Factor loadings are presented in Table 3. Correlations between factors ranged from 0.47 to 0.50. Results indicate that the BFS demonstrates good reliability (Cronbach's alpha: F1 = 0.79, F2 = 0.80, F3 = 0.78; Coefficient omega: F1 = 0.83, F2 = 0.87, F3 = 0.84).

CFA performed with dataset 2 ($n = 871$) confirmed the structure of the BFS as a three-factorial model ($\chi 2 = 1682.16$, df = 227, $p < .001$, RMSEA = 0.066 [90 % CI = 0.063/0.069]; CFI = 0.969, TLI = 0.966). Inspection of factor loadings revealed that all items loaded strongly (above 0.80) on their respective factors. Standardised factor loadings are presented in Table 3. The configural ($\chi 2 = 3025.98$, df = 457, $p < .001$, RMSEA = 0.081 [90 % CI = 0.078/0.084]; CFI = 0.865, TLI = 0.849) and metric ($\chi 2 = 3037.49$, df = 474, $p < .001$, RMSEA = 0.083 [90 % CI = 0.081/0.086]; CFI = 0.856, TLI = 0.845) models of invariance indicated an acceptable model fit based on the differences in the CFI, TLI, and RMSEA values (ΔCFI = 0.009, ΔTLI = 0.004, ΔRMSEA = 0.002). Therefore, the BFS has factorial invariance across gender.

Based on the content of items included in each factor, Factor 1 can be labelled "mental fatigue" (6 items), Factor 2 – "impaired cognitive acuity" (9 items), and Factor 3 – "confusion" (8 items). Correlations between factors ranged from 0.72 to 0.75.

3.3. Pre-matching independent samples t-tests, fuzzy matching, and post-matching independent samples t-tests

The independent samples t-tests (before matching) showed no statistically significant differences between groups on all three subscales, including mental fatigue (COVID+ group: $M = 12.68$, $SD = 5.06$; COVID- group: $M = 12.62$, $SD = 5.03$, $t[1160] = 0.16$, $p = .87$), impaired cognitive acuity (COVID+ group: $M = 13.16$, $SD = 7.43$; COVID- group: $M = 13.06$, $SD = 6.87$, $t[1160] = 0.20$, $p = .42$), and confusion (COVID+ group: $M = 9.23$, $SD = 6.64$; COVID- group: $M = 9.66$, $SD = 6.77$, t

[1] Preliminary analysis showed no significant differences between dataset 1 and dataset 2 on all study variables.

Table 3
Standardised factor loadings for the three factors (mental fatigue, impaired cognitive acuity, and confusion) of the Brain Fog Scale (BFS).

No	Scale item in English (and Polish)	PCA			CFA		
		F1	F2	F3	F1	F2	F3
1.	My thinking has been slow. (Odczuwałem/am spowolnienie myślenia.)	0.56			0.95		
2.	I have felt mentally exhausted. (Odczuwałem/am zmęczenie psychiczne.)	0.82			0.85		
3.	I have felt fatigued. (Czułem/am się wyczerpany/a.)	0.86			0.92		
4.	I have been easily distracted. (Łatwo się rozpraszałem/am.)	0.60			0.92		
5.	I have found myself getting annoyed. (Byłem/am rozdrażniony/a.)	0.63			0.81		
6.	I have felt sleepy. (Byłem/am ospały/a.)	0.75			0.89		
7.	I have found it difficult to remember and understand new information. (Miałem/am problemy z zapamiętywaniem i przyswajaniem nowych informacji.)		0.60			0.93	
8.	I have found myself forgetting certain words, such as the names of objects. (Zdarzało mi się zapomnieć pewnych słów, takich jak nazwy przedmiotów.)		0.82			0.81	
9.	I have found it difficult to think logically. (Miałem/am problemy z logicznym myśleniem.)		0.70			0.93	
10.	I have found it difficult to concentrate. (Miałem/am problemy z koncentracją uwagi.)		0.48			0.95	
11.	I couldn't think clearly. (Nie mogłem/am jasno myśleć.)		0.52			0.95	
12.	I have had a hard time finding the right words. (Miałem/am problemy z doborem właściwych słów.)		0.77			0.91	
13.	I have found it difficult to organise my thoughts. (Miałem/am problemy z formułowaniem myśli.)		0.73			0.93	
14.	I have felt like my mind's gone blank. (Miałem/am uczucie pustki w głowie.)		0.51			0.93	
15.	I have found it difficult to understand words when reading. (Miałem trudności ze zrozumieniem przeczytanych słów.)		0.49			0.93	
16.	I have had a hard time understanding what others say. (Miałem/am trudności ze zrozumieniem tego co mówią do mnie inni.)			0.53			0.92
17.	I have been daydreaming. (Miałem/am uczucie śnienia na jawie.)			0.85			0.91
18.	I have felt spacey. (Miałem/am uczucie oderwania od rzeczywistości.)			0.81			0.96
19.	I have felt confused. (Czułem/am się zdezorientowany/a.)			0.58			0.97
20.	I have experienced thought blocking. (Zdarzało mi się „zawieszać się".)			0.48			0.93
21.	I have felt lost. (Czułem/am się zagubiony/a.)			0.52			0.93
22.	I have felt absent, as if I were living in my own world. (Miałem/am uczucie nieobecności, tak jakbym żył/a w swoim świecie.)			0.87			0.95
23.	My thoughts have been moving quickly. (Miałem/am gonitwę myśli.)			0.50			0.84

Note. CFA = Confirmatory Factor Analysis; F1 = mental fatigue subscale; F2 = impaired cognitive acuity subscale; F3 = confusion subscale; PCA = Principal Component Analysis. All factor loadings are statistically significant at $p < .05$.

[1160] = 0.93, $p = .36$).

However, it was assumed that the COVID+ individuals would differ from the COVID- individuals on a number of covariates (i.e., age, gender, perceived weight, physical activity, healthy eating, unhealthy eating, and general health status). These potential confounding variables (covariates) were used to estimate a propensity score (ranging from 0 to 1) that represents each participant's likelihood of being assigned to the treatment group. The propensity score is then used to generate a matched sample of treatment and control respondents. Thus, the propensity score is a balancing score of covariates, meaning the distribution of variables is equivalent for the participants from treatment and control groups. After calculating the propensity scores for each participant, a matching procedure was employed to match participants from both samples. The matching procedure utilised in this study was 1:1 matching with FUZZ = 0.1 (total = 265 matches).

With the new matched sample, an independent samples *t*-test was performed to investigate whether COVID+ individuals had significantly different brain fog levels compared with their COVID- counterparts. In line with our prediction, we found that the COVID+ group scored significantly higher on all three BFS subscales, including mental fatigue (COVID+ group: $M = 12.68$, $SD = 5.06$; COVID- group: $M = 8.62$, $SD = 4.63$, $t[516] = 9.52$, $p < .001$, M difference = 4.06 [95 % CI: 3.22, 4.90], SE difference = 0.43, Cohen's $d = 0.84$ [95 % CI: 0.66, 1.02]), impaired cognitive acuity (COVID+ group: $M = 13.16$, $SD = 7.43$; COVID- group: $M = 7.81$, $SD = 6.18$, $t[516] = 8.94$, $p < .001$, M difference = 5.35 [95 % CI: 4.17, 6.53], SE difference = 0.60, Cohen's $d = 0.78$ [95 % CI: 0.60, 0.96]), and confusion (COVID+ group: $M = 9.22$, $SD = 6.64$; COVID- group: $M = 5.18$, $SD = 5.71$, $t[516] = 7.43$, $p < .001$, M difference = 4.05 [95 % CI: 2.98, 5.12], SE difference = 0.55, Cohen's $d = 0.65$ [95 % CI: 0.48, 0.83]).

4. Discussion

Brain fogginess is a common complaint among various patients; however, the phenomenon has not been sufficiently explored in the literature (Lucius, 2021). Recently, we have witnessed a rapid rise in the number of research studies in the area, predominantly due to the fact that brain fog is listed as a common long COVID condition, regardless of the clinical severity of illness (Krishnan et al., 2022). However, despite the increased interest in the topic, the construct of brain fog remains ill-defined and a common method of assessment of the condition is lacking. Therefore, the main aim of the study was to develop and validate a reliable, based on a clear definition, self-report measure of brain fog for

use in clinical and research settings. A 23-item scale was developed to measure the concept of brain fog, defined as a cognitive dysfunction characterised by problems with concentration and memory, inattention, confusion, difficulty understanding spoken and written language, reduced mental acuity, and mental fatigue. The Brain Fog Scale (BFS) was found to be best captured by a three-factor solution, with six items loading on the mental fatigue factor, nine items loading on the impaired cognitive acuity factor, and eight items loading on the confusion factor. The results of the present study also showed that individuals who acquired a COVID-19 infection had significantly elevated scores on all three BFS subscales compared with non-infected matched controls.

In order to address the second objective of the present investigation, we examined the factor structure of the BFS using principal component analysis (PCA), followed by confirmatory factor analysis (CFA). PCA results revealed the presence of three factors with eigenvalues exceeding 1 and CFA results confirmed this three-factor solution. Based on the content of items included in each factor, Factor 1 was labelled "mental fatigue", Factor 2 – "impaired cognitive acuity", and Factor 3 – "confusion". More specifically, mental fatigue refers to the feeling of exhaustion, which may affect one's performance and mood. Individuals with increased scores on the mental fatigue subscale reported, among others, having been easily distracted and annoyed. Impaired cognitive acuity is characterised by difficulty in thinking clearly, concentrating, remembering, and learning new things. The final factor, confusion, refers to the feeling of disorientation and detachment from one's surroundings. These findings indicate that brain fog is a multi-dimensional phenomenon, which should be taken into account in future theoretical and empirical work as well as the scoring of the scale. The results also confirmed good internal consistency and factorial invariance across gender, indicating that the underlying construct is the same for women and men. The intended purpose of the scale is the assessment of symptom severity and as an estimator of change in intervention studies. More empirical work is needed to determine the cut-off values for each subscale above which a clinical intervention may be required.

Based on prior research (e.g., Butardo et al., 2022; Krishnan et al., 2022; Taquet et al., 2022; Theoharides et al., 2021), we predicted that individuals who acquired COVID-19 infection would have elevated levels of brain fog, compared with individuals who never tested positive for COVID-19. Since the BFS turned out to be a multi-dimensional measure, we compared participants' scores on the three subscales of the BFS separately. To test the prediction, we employed fuzzy matching using propensity score. Fuzzy matching is a non-experimental technique which allowed us to reduce bias in background characteristics (covariates) between COVID+ and COVID- samples. Post-matching independent samples *t*-tests revealed statistically significant differences between COVID+ and COVID- samples, with COVID+ individuals experiencing more mental fatigue, impaired cognitive acuity, and confusion symptoms than their COVID- counterparts. The magnitude of the difference between groups was medium to large, which implies that brain fog is a substantial post-COVID problem.

This study is not free from limitations. First, all data were collected via self-report questionnaires, including information with regards to COVID-19 infection. Therefore, it is possible that some participants classified in the COVID- group had asymptomatic COVID and, as such, did not test for the presence of the virus. However, not all self-report measures are inferior to clinician-administered ones, as recently demonstrated in the context of psychological distress assessment (Hyland & Shevlin, 2023). More specifically, clinician-administered measures of patients' subjective experiences may produce higher levels of measurement error due to there being two sources of measurement error – the interviewer and the interviewee. In light of this evidence, our self-report approach to brain fog assessment should not be regarded as a limitation. Second, although we tested whether the underlying construct is the same for women and men, the sample used was relatively small for this purpose. Therefore, future studies should utilise larger samples to assess factorial invariance across gender. Another limitation of the study is that our original dataset was gender imbalanced and so we had to collect additional data among men to remedy this issue. Future studies should use real-time monitoring of data collection to ensure equal representation of different demographics within one sample. We also recommend that future studies are conducted with more diverse populations, including hospitalised and non-hospitalised patients with conditions or taking medications which may trigger brain fogginess. Despite those limitations, we recruited a large sample of participants, with a very high response rate. In addition, our comparisons between COVID+ and COVID- individuals were based upon a matched sample (1:1 matching), which allowed us to control for treatment selection bias.

5. Conclusions

Overall, the BFS is a 23-item, easy-to-use brain fog measure with good psychometric properties. PCA and CFA results indicate that the BFS has three dimensions (mental fatigue, impaired cognitive acuity, and confusion) and hence scoring should rely on the instrument's subscale scores. Individuals who acquired a COVID-19 infection had significantly elevated levels of mental fatigue, impaired cognitive acuity, and confusion compared with non-infected matched controls. Future studies should evaluate the psychometric properties of the BFS using populations drawn from various settings, including hospitalised and non-hospitalised patients with conditions that may lead to brain fog symptoms, such as postural tachycardia syndrome (POTS) (see Ross et al., 2013) and CFS (see Ocon, 2013). Future studies should also determine cut-off scores for the three subscales to identify individuals in need of clinical interventions. The BFS, as the only validated self-report measure of brain fog, can also be used in studies investigating long COVID conditions, especially where large samples are being recruited. This would allow for direct comparisons across different research studies and hence more reliable and clinically useful meta-analyses.

Statement

During the preparation of this work, the authors did not use any AI-assisted technologies.

CRediT authorship contribution statement

Agata Debowska: Conceptualisation, Methodology, Investigation, Formal Analysis, Data curation, Writing – Original draft, Writing – Review & editing.

Daniel Boduszek: Investigation, Formal Analysis, Writing – Original draft, Writing – Review & editing.

Marek Ochman: Conceptualisation, Investigation.

Tomasz Hrapkowicz: Conceptualisation, Investigation.

Martyna Gaweda: Investigation.

Anastazja Pondel: Investigation.

Beata Horeczy: Conceptualisation, Investigation.

Declaration of competing interest

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Data availability

Data will be made available on request.

References

Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychological Bulletin, 107*(2), 238–246. https://doi.org/10.1037/0033-2909.107.2.238

Browne, M. W., & Cudeck, R. (1993). Alternative ways of assessing model fit. In K. Bollen, & J. Long (Eds.), *Testing structural equation models* (pp. 136–162). SAGE Publications.

Butardo, N. D., Coronel, M. F. D., Dino, A. M. O., Ritz, T., Mendoza, F., Domingo, O. K. D. S., … Ligsay, A. D. (2022). Clearing the fog: A systematic review on cognitive dysfunction in COVID-19. *medRxiv*. https://doi.org/10.1101/2022.05.24.22275552

Callan, C., Ladds, E., Husain, L., Pattinson, K., & Greenhalgh, T. (2022). 'I can't cope with multiple inputs': A qualitative study of the lived experience of 'brain fog'after COVID-19. *BMJ Open, 12*(2), Article e056366. https://doi.org/10.1136/bmjopen-2021- 056366

Chen, F. F. (2007). Sensitivity of goodness of fit indexes to lack of measurement invariance. *Structural Equation Modeling: A Multidisciplinary Journal, 14*(3), 464–504. https://doi.org/10.1080/10705510701301834

Christodoulou, C., DeLuca, J., Lange, G., Johnson, S. K., Sisto, S. A., Korn, L., & Natelson, B. H. (1998). Relation between neuropsychological impairment and functional disability in patients with chronic fatigue syndrome. *Journal of Neurology, Neurosurgery & Psychiatry, 64*(4), 431–434. https://doi.org/10.1136/jnnp.64.4.431

De Frel, D. L., Atsma, D. E., Pijl, H., Seidell, J. C., Leenen, P. J., Dik, W. A., & Van Rossum, E. F. (2020). The impact of obesity and lifestyle on the immune system and susceptibility to infections such as COVID-19. *Frontiers in Nutrition, 7*, Article 597600. https://doi.org/10.3389/fnut.2020.597600

Guertin, C., Pelletier, L., & Pope, P. (2020). The validation of the Healthy and Unhealthy Eating Behavior Scale (HUEBS): Examining the interplay between stages of change and motivation and their association with healthy and unhealthy eating behaviors and physical health. *Appetite, 144*, 104487. https://doi.org/10.1016/j.appet.2019.104487

Hamer, M., Kivimäki, M., Gale, C. R., & Batty, G. D. (2020). Lifestyle risk factors, inflammatory mechanisms, and COVID-19 hospitalization: A community-based cohort study of 387,109 adults in UK. *Brain, Behavior, and Immunity, 87*, 184–187. https://doi.org/10.1016/j.bbi.2020.05.059

Hays, R. D., Spritzer, K. L., Thompson, W. W., & Cella, D. (2015). U.S. general population estimate for "excellent" to "poor" self-rated health item. *Journal of General Internal Medicine, 30*(10), 1511–1516. https://doi.org/10.1007/s11606-015-3290-x

Hyland, P., & Shevlin, M. (2023). Clinician-administered interviews should not be considered the 'gold standard' method of assessing psychological distress. *PsyArXiv*. https://doi.org/10.31234/osf.io/9f8ah

Kaiser, H. F. (1960). The application of electronic computers to factor analysis. *Educational and Psychological Measurement, 20*(1), 141–151. https://doi.org/10.1177/001316446002000116

Krishnan, K., Lin, Y., Prewitt, K. R. M., & Potter, D. A. (2022). Multidisciplinary approach to brain fog and related persisting symptoms post COVID-19. *Journal of Health Service Psychology, 48*(1), 31–38. https://doi.org/10.1007/s42843-022-00056-7

Kverno, K. (2021). Brain fog: A bit of clarity regarding etiology, prognosis, and treatment. *Journal of Psychosocial Nursing and Mental Health Services, 59*(11), 9–13. https://doi.org/10.3928/02793695-20211013-01

Lucius, K. (2021). "Brain fog": Exploring a symptom commonly encountered in clinical practice. *Alternative and Complementary Therapies, 27*(1), 23–30. https://doi.org/10.1089/act.2020.29313.klu

McDonald, R. P. (1999). *Test theory: A unified approach*. Erlbaum.

Milton, K., Bull, F. C., & Bauman, A. (2011). Reliability and validity testing of a single-item physical activity measure. *British Journal of Sports Medicine, 45*(3), 203–208. https://doi.org/10.1136/bjsm.2009.068395

Muthén, L. K., & Muthén, B. O. (1998–2015). *Mplus user's guide (7th edition)*. Muthén & Muthén.

Ocon, A. J. (2013). Caught in the thickness of brain fog: Exploring the cognitive symptoms of chronic fatigue syndrome. *Frontiers in Physiology, 4*, 63. https://doi.org/10.3389/fphys.2013.00063

Ross, A. J., Medow, M. S., Rowe, P. C., & Stewart, J. M. (2013). What is brain fog? An evaluation of the symptom in postural tachycardia syndrome. *Clinical Autonomic Research, 23*(6), 305–311. https://doi.org/10.1007/s10286-013-0212-z

Rubin, D. B. (2006). *Matched sampling for casual effects*. Cambridge University Press.

Steiger, J. H. (1990). Structural model evaluation and modification: An interval estimation approach. *Multivariate Behavioral Research, 25*(2), 173–180. https://doi.org/10.1207/s15327906mbr2502_4

Taquet, M., Sillett, R., Zhu, L., Mendel, J., Camplisson, I., & Dercon, Q. (2022). Neurological and psychiatric risk trajectories after SARS-CoV-2 infection: An analysis of 2-year retrospective cohort studies including 1 284 437 patients. *The Lancet Psychiatry*. https://doi.org/10.1016/S2215-0366(22)00260-7

Theoharides, T. C., Cholevas, C., Polyzoidis, K., & Politis, A. (2021). Long-COVID syndrome-associated brain fog and chemofog: Luteolin to the rescue. *Biofactors, 47*(2), 232–241. https://doi.org/10.1002/biof.1726

Tucker, L. R., & Lewis, C. (1973). A reliability coefficient for maximum likelihood factor analysis. *Psychometrika, 38*, 1–10. https://doi.org/10.1007/BF02291170

Van de Schoot, R., Lugtig, P., & Hox, J. (2012). A checklist for testing measurement invariance. *European Journal of Developmental Psychology, 9*(4), 486–492. https://doi.org/10.1080/17405629.2012.686740

Zhou, M., Zhang, N., Zhang, M., & Ma, G. (2020). Culture, eating behavior, and infectious disease control and prevention. *Journal of Ethnic Foods, 7*(1), 1–7. https://doi.org/10.1186/s42779-020-00076-y

Ziauddeen, N., Gurdasani, D., O'Hara, M. E., Hastie, C., Roderick, P., Yao, G., & Alwan, N. A. (2021). P108 characteristics of long COVID: Findings from a social media survey. *Journal of Epidemiology and Community Health, 75*, A90. https://jech.bmj.com/content/75/Suppl_1/A90.1.