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Persistence of Cognitive Difficulties in Adults Three Years After COVID-19 Infection

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Abstract

The COVID-19 pandemic has left millions worldwide with persistent cognitive difficulties, making long-term studies essential to understand their trajectory and inform rehabilitation strategies. This research is presented within the context of Long COVID, emphasizing that cognitive symptoms (including deficits in attention, memory, and executive functions) are reported even in non-hospitalized individuals, yet longitudinal evidence beyond two years remains scarce. An observational, cross-sectional, and retrospective design was applied to a sample of 297 adults with their cognition assessed, divided into mild, moderate, and severe COVID-19 groups, and evaluated using standardized cognitive tests. Findings showed that cognitive performance declined with increasing severity of COVID-19 symptoms, particularly in divided attention, working memory, executive control, verbal fluency, recognition memory, and general intelligence. Age consistently predicted lower scores across cognitive domains, especially in moderate and severe groups, whereas education level did not exert a significant protective effect. The study shows that cognitive deficits can persist at least three years after infection, affecting older adults and those with the more severe symptoms. These results highlight the need for long-term neuropsychological monitoring and individualized rehabilitation strategies to mitigate impacts on autonomy and quality of life.

Keywords: Long COVID; COVID-19; cognition; neuropsychological tests

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1. Introduction

The COVID-19 pandemic, caused by the SARS-CoV-2 virus, emerged as a global public health emergency with impacts that extend far beyond the acute phase of infection. Since its first reports in 2019, the disease has demonstrated high transmissibility and significant lethality, particularly among vulnerable populations, while also generating a growing number of prolonged clinical conditions that continue to substantially affect the physical, mental, and cognitive health of millions of individuals worldwide [1–4].

Among these conditions, post-COVID-19 syndrome—commonly referred to as Long COVID—is characterized by the persistence of symptoms for weeks or months after the initial phase of infection [5,6]. The most frequently reported manifestations include fatigue, dyspnea, sleep disturbances, musculoskeletal pain, mood alterations, neuropsychiatric symptoms, and, notably, cognitive impairments [7–9]. This cluster of manifestations poses increasing challenges to healthcare systems, demanding physical, psychological, and

neurocognitive rehabilitation efforts, even among individuals who did not present severe forms of the disease [10–13].

In the field of neuroscience, investigations have demonstrated that the effects of SARS-CoV-2 on the central nervous system involve complex pathophysiological mechanisms, including neuroinflammation, hypoxia, endothelial dysfunction, and blood–brain barrier disruption [14–17]. These processes may result in structural and functional brain alterations with significant clinical implications. Evidence indicates that the cognitive domains most frequently affected include sustained attention, working memory, processing speed, reasoning, and executive functions [18–22], with more pronounced deficits observed among individuals infected with specific viral strains, such as the original and Alpha variants [12].

It is important to emphasize that such impairments are not limited to hospitalized patients or those with severe clinical presentations [23]. Recent findings from our group [24] revealed deficits in attention, verbal memory, and processing speed in individuals who experienced mild to moderate COVID-19, including those who did not require hospitalization. Another study found that deficits can be persistent even among individuals who were not severely ill; nonetheless, outcomes appear heterogeneous, with many recovering within the first year while others experience deficits for longer periods [25].

These findings suggest that the mechanisms underlying cognitive alterations may be more strongly associated with systemic and neuroinflammatory processes than exclusively with the consequences of hospitalization, hypoxia, or prolonged sedation [25–27]. They highlight the multifactorial nature of post-COVID cognitive sequelae and reinforce the importance of long-time research to better understand their persistence and underlying mechanisms.

Despite advances in early investigations, a substantial gap remains regarding the temporal presence of these manifestations. The literature lacks robust and systematic data on the persistence of cognitive deficits over longer periods, particularly beyond two years after the initial infection. This limitation compromises the planning of long-term healthcare policies, the design of rehabilitation strategies, and the broader understanding of COVID-19's long-term effects.

Given this context, the present study investigated the presence of persistent cognitive alterations in adults at least three years after COVID-19 infection. By expanding knowledge about the prolonged effects of the disease, this study aims to contribute to the development of strategies for clinical monitoring, neuropsychological intervention, and public health policies focused on rehabilitation and the promotion of cognitive well-being in the affected population.

A hypothesis is that differences in cognitive performance following COVID-19 may not only reflect the direct severity of the acute illness but also the distinct neurobiological pathways engaged at different levels of disease burden. For instance, severe cases might be more strongly associated with hypoxic or vascular mechanisms, whereas mild to moderate cases could primarily involve neuroinflammatory responses or immune dysregulation [28]. These differences under severity, as seen, show some level of inconsistency in previous literature. The divergent mechanisms may lead to qualitatively different cognitive profiles, suggesting that the relationship between illness severity and long-term cognitive outcomes is not strictly linear but instead shaped by multiple overlapping personal and sociodemographic processes, such as education.

2. Materials and Methods

2.1. Participants

This was an observational, with a cross-sectional and retrospective design, based on a convenience sample composed of individuals selected from multiple strata made of public and private hospital settings. Another study has already been published with the same sample [24]. As described in that study, statistical power was calculated using the G*Power

software (version 3.1.9.7). Parameters were set at $\alpha = 0.05$, a medium effect size of $f^2 = 0.18$, and 10 predictors, with the target power established at 0.80. Based on these criteria, the estimated sample size required for that study was approximately 300. In that study [24], 302 volunteers treated at the institutions agreed to participate.

From this initial sample, 297 agreed to be reevaluated for the present investigation ($n = 297$). There was an equitable distribution between sexes: 148 men (49.8%) and 149 women (50.2%). Participants were allocated into three distinct groups according to the severity of the clinical presentation during COVID-19 infection:

(a) Mild/asymptomatic group ($n = 101$): individuals with mild symptoms (e.g., rhinorrhea, headache, isolated fever) or asymptomatic cases who did not require specialized medical care;
(b) Moderate gravity group ($n = 101$): individuals presenting persistent fever, cough, and progressive respiratory difficulty, requiring hospitalization in a general ward;
(c) Severe group ($n = 95$): individuals diagnosed with Severe Acute Respiratory Syndrome (SARS), with dyspnea, persistent chest pain, and oxygen saturation below 90%, requiring admission to the intensive care unit (ICU).

2.2. Elegibility Criteria

Participants were included if they met the following criteria: (a) Minimum age of 18 years; (b) Previous diagnosis of COVID-19 confirmed by laboratory testing (RT-PCR or serological test); (c) No self-reported cognitive complaints prior to COVID-19 infection; (d) Participation in the initial assessment of the previous study [24]; (e) At least 36 months elapsed since COVID-19 infection; and (f) Clinical and cognitive conditions adequate for completing the proposed instruments. Individuals with a history of previously diagnosed neurological disorders, severe sequelae from accidents or traumatic brain injuries, psychiatric comorbidities, or preexisting cognitive complaints were excluded to minimize potential confounding effects on neurocognitive performance. Formal consent was collected from all participants through digital signature of a consent form.

2.3. Data Collection and Measures

Data collection was conducted online and individually, via the Google Meet® platform, by trained evaluators under the supervision of the research team. Sessions were scheduled in advance with participants, ensuring appropriate conditions for assessment, such as a quiet environment, stable internet connection, and absence of external interferences. Initially, participants completed a structured sociodemographic questionnaire, which included information on age, education (years of schooling), occupation, general medical history, and details related to COVID-19 infection, including symptom severity, type of treatment received, and time elapsed since infection. Subsequently, standardized instruments for remote cognitive assessment were administered, targeting different cognitive domains:

- Intelligence Quotient (IQ) obtained through the Vocabulary and Matrix Reasoning subtests of the Wechsler Abbreviated Scale of Intelligence (WASI) [29].
- Attention and working memory through verbal stimuli were assessed using the Digit Span subtest—Forward and Backwards—of the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III) [30].
- Divided attention through visual stimuli was measured with a computerized divided attention test (Online Attention Test—AOL), requiring simultaneous focus on multiple stimuli [31].
- Verbal fluency was assessed using phonemic and semantic fluency tests (FAS), requiring the rapid production of words based on an initial letter or semantic category [32].

- Short-term visual recognition memory was measured using the Computerized Recognition Memory Test (TEM-R), which presents visual stimuli to be recognized after prior exposure [33].

All participants were informed about the study objectives and procedures and provided consent via digital signature of the informed consent form, in accordance with the ethical guidelines of Resolution No. 510/2016 of the Brazilian National Health Council. The project was previously approved by the institutional Research Ethics Committee.

2.4. Data Analysis

Statistical analyses were conducted using Jamovi® software (version 2.3.26). Descriptive measures were first calculated, including mean, standard deviation, minimum and maximum values, range, as well as absolute and relative frequencies, in order to characterize the distribution of the studied variables.

Normality of distributions was tested using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Bartlett's test. For comparisons among the three groups defined according to COVID-19 severity, one-way Analysis of Variance (ANOVA) was performed, followed by post hoc tests when applicable. In cases where the assumptions of normality and homoscedasticity were violated, the Kruskal–Wallis test was employed, with adjusted multiple comparisons.

Associations between categorical variables were explored using the Chi-square test (χ^2) of association and Fisher's exact test, when applicable (i.e., when one of the variables or groups had fewer than five units). Additionally, multiple linear regression was performed to identify relevant predictors, with results reported as the coefficient of determination (R^2) and the percentage of variance explained by the predictors of interest. All tests were two-tailed, and a significance level of 5% ($p < 0.05$) was adopted for all inferential analyses.

A direct statistical comparison between the findings of the first study [24] and those of the present investigation was avoided, as this was not designed as a longitudinal study. Nevertheless, considering the hypothesis that cognitive deficits may persist among individuals with prior COVID-19—and that such deficits could differ according to illness severity—along with the opportunity provided by participant accessibility, a new invitation was extended to take part in this cross-sectional study.

3. Results

3.1. Participants

The sample consisted of 297 participants, with a balanced distribution between genders, comprising 148 men (49.8%) and 149 women (50.2%). The mean age was 50.7 years (SD = 13.4), ranging from 18 to 74 years, while the mean educational level was 12.8 years (SD = 3.5), with values ranging from 4 to 22 years (Table 1). Regarding the severity of COVID-19 symptoms, 101 participants (34.0%) reported mild symptoms, 101 (34.0%) presented moderate symptoms, and 95 (32.0%) reported severe symptoms. Thus, the majority of the sample (68.0%) experienced mild or moderate symptoms, whereas 32.0% of individuals presented symptoms classified as severe. This distribution highlights the heterogeneity of the disease's impact among participants.

As seen in Table 1, no statistically significant association was found between symptom severity and sex of the participants ($\chi^2 = 0.34$; $p = 0.842$). However, there was a statistically significant association between symptom severity and age ($\chi^2 = 21.0$; $p < 0.001$), as well as between symptom severity and educational level ($\chi^2 = 31.7$; $p < 0.001$). The data show that individuals with milder symptoms tended to be younger ($M = 46.7$; SD = 12.4; 95% CI: 44.3–49.2), particularly when compared to participants with moderate symptoms ($W = 3.4$; $p = 0.043$), who were older ($M = 50.6$; SD = 14.0; 95% CI: 47.9–53.4), and also when

compared to participants with severe symptoms ($W = 6.5$; $p < 0.001$), who were significantly older ($M = 55.0$; SD = 12.5; 95% CI: 52.5–57.6). In summary, the data indicate that greater age is associated with greater severity of COVID-19 symptoms.

Table 1. Sociodemographic and clinical characteristics of the sample.

	Total			Mild Symptoms			Moderate Symptoms			Severe Symptoms			χ^2	*p*-Value
	n	**%**	**FR**	***n***	**%**	**RF**	***n***	**%**	**FR**	***n***	**%**	**RF**		
Men	148	100%	49.8%	48	32.4%	47.5%	52	35.1%	51.5%	48	32.4%	50.5%	0.34	0.842
Women	149	100%	50.2%	53	35.6%	52.5%	49	32.9%	48.5%	47	31.5%	49.5%		
	n	***M***	**SD**	***n***	***M***	**SD**	***n***	***M***	**SD**	***n***	***M***	**SD**	**Fisher**	***p***
Age	297	50.7	13.4	101	46.7	12.4	101	50.6	14.0	95	55.0	12.5	21.0	<0.001
Education years	297	12.8	3.5	101	14.4	2.6	101	12.4	3.4	95	11.5	3.9	31.7	<0.001
Hospitalization	101	8.2	3.9	-	-	-	101	8.2	3.9	-	-	-	-	-
Days in CTI	196	7.0	9.2	-	-	-	101	0.0	0.0	95	14.4	8.2	-	-

Hospitalization data is unavailable for participants with mild or severe symptoms. χ^2: chi-square of association; Fisher: Fisher Exact Test; *M*: mean; SD: standard deviation; RF: relative frequency in percentage.

With regard to educational level, the data show that individuals with milder symptoms tended to have more years of schooling ($M = 14.4$; SD = 2.6; 95% CI: 13.8–14.9), particularly when compared to participants with moderate symptoms ($W = -6.1$; $p < 0.001$), who had fewer years of education ($M = 12.4$; SD = 3.4; 95% CI: 11.7–13.1), and also when compared to participants with severe symptoms ($W = -7.3$; $p < 0.001$), who had even fewer years of education ($M = 11.5$; SD = 3.9; 95% CI: 10.7–12.4). Overall, the data demonstrate that lower educational attainment is associated with greater severity of COVID-19 symptoms.

Data on hospitalization time were available only for the group with moderate COVID-19 symptoms (Table 1). In this group ($n = 101$), the mean number of hospitalization days was 8.24 (SD = 3.9), ranging from 0 to 17 days. Regarding intensive care unit (ICU) stay, no participant in the moderate group had a history of ICU admission. In contrast, in the severe group ($n = 95$), the mean ICU stay was 14.4 days (SD = 8.2), ranging from 0 to 38 days. These findings indicate that the need for intensive care was restricted to individuals with greater symptom severity, with wide variation in length of stay, reflecting the heterogeneity of clinical severity within this group.

3.2. Analysis of Cognitive Performance with the Severity of COVID Symptoms

The results presented in Table 2 show that participants' cognitive performance tends to decrease as COVID-19 symptom severity increases (see Table 2). Participants with severe symptoms obtained lower scores compared to those with mild symptoms, who presented higher scores.

Table 2. Cognitive performance according to the severity of COVID-19 symptoms.

Cognitive Test	Cognitive Domain	COVID-19 Symptoms				Stat.	*p*
		Total	Mild	Moderate	Severe		
		***M* (SD)**	***M* (SD)**	***M* (SD)**	***M* (SD)**		
IQ (WASI)	General intelligence	95.8 (5.3)	96.7 (4.2)	95.3 (5.4)	95.4 (6.1)	7.3 [1]	0.026
AOL	Divided attention	36.1 (12.6)	44.5 (8.9)	36.1 (11.3)	27.3 (11.2)	71.0 [2]	<0.001
DS Forward	Working Memory	9.6 (2.1)	10.6 (1.4)	9.3 (2.1)	9.0 (2.3)	35.6 [1]	<0.001
DS Backwards	Attention/executive control	8.1 (2.0)	9.0 (1.3)	7.6 (2.2)	7.5(2.1)	40.78 [1]	<0.001
FAS	Verbal fluency	13.7 (3.3)	14.6 (1.7)	14.3 (4.3)	12.2 (2.8)	32.9 [1]	<0.001
TEM-R	Recognition memory	22.9 (4.6)	23.9 (3.7)	23.2 (4.9)	21.6 (4.9)	9.9 [1]	0.007

[1] Kruskal–Wallis test. [2] One-way ANOVA for heterogeneous samples. AOL: Online Attention; DS: Digit Span; FAS: Phonemic and Semantic Verbal Fluency; IQ: Intelligence Quotient; *M*: mean; Stat.: statistic results for Kruskal–Wallis test or One-way ANOVA; SD: standard deviation; WASI: Wechsler Abbreviated Scale of Intelligence.

Comparative analysis of the Intelligence Quotient (IQ) across the three groups stratified by COVID-19 symptom severity (mild, moderate, and severe) reveals statistically significant differences ($p < 0.05$). These findings suggest that, in the present sample, overall intellectual performance did vary significantly as a function of disease severity.

Analysis of specific cognitive functions revealed statistically significant differences between groups stratified by COVID-19 symptom severity. In divided attention, significant differences were observed across the three groups ($F = 71.0$; $p < 0.001$). Multiple comparisons indicated differences between all pairs: mild vs. moderate symptoms ($t = 5.9$; $p < 0.001$), mild vs. severe ($t = 11.8$; $p < 0.001$), and moderate vs. severe ($t = 5.5$; $p < 0.001$). Participants with severe symptoms showed the lowest scores, while those with mild symptoms achieved the best performance, suggesting a gradual impact of disease severity on the ability to shift and sustain attention.

In verbal working memory (Digit Span Forward subtest), significant group differences were also observed ($H = 35.6$; $p < 0.001$). Participants with mild symptoms scored significantly higher than those with moderate ($z = -6.8$; $p < 0.001$) and severe symptoms ($z = -7.8$; $p < 0.001$). The difference between the moderate and severe groups, although indicating lower scores in the more severe cases, did not reach statistical significance ($z = -0.8$; $p = 0.836$).

Similar results were found for attentional control (Digit Span Backward subtest), with significant differences across groups ($H = 40.8$; $p < 0.001$). Participants with mild symptoms performed better than those with moderate ($z = -7.8$; $p < 0.001$) and severe symptoms ($z = -7.8$; $p < 0.001$), with no significant differences between the moderate and severe groups ($z = -0.2$; $p = 0.994$).

Verbal fluency also showed significant group differences ($H = 32.9$; $p < 0.001$). Participants with severe symptoms obtained significantly lower scores than those with mild ($z = -8.6$; $p < 0.001$) and moderate symptoms ($z = -5.5$; $p < 0.001$), while no differences were observed between the mild and moderate groups ($z = 0.6$; $p = 0.897$).

Finally, in the Recognition Memory Test (TEM-R), a significant difference was identified among the groups ($H = 9.8$; $p = 0.007$). Post hoc analysis revealed that only the comparison between mild and severe groups showed a significant difference ($z = -4.4$; $p = 0.005$), with lower scores observed in participants with more severe disease. Overall, the results indicate a consistent pattern of decline in attentional, memory, and executive performance proportional to increasing severity of COVID-19 symptoms, suggesting a possible residual neurocognitive effect of the disease.

3.3. Association Between Sociodemographic Variables Age and Education with Cognitive Performance

The results presented in Table 3 show the multiple regression analyses performed for each cognitive variable, considered as the dependent variable, in relation to the sociodemographic predictors age and educational level. Analyses were stratified according to the three levels of COVID-19 symptom severity, allowing assessment of the predictive effects of these variables on cognitive performance within each group.

For the Digit Span Forward subtest, which assesses verbal working memory, the models were statistically significant for all three groups: mild (Adj. $R^2 = 29\%$; $p < 0.001$), moderate (Adj. $R^2 = 31.7\%$; $p < 0.001$), and severe (Adj. $R^2 = 35.4\%$; $p < 0.001$). Age showed a negative and significant effect on performance across all groups, indicating that increasing age was associated with reduced working memory scores. This effect was most pronounced among individuals with severe symptoms, whose age-related impact was, on average, 55.2% greater compared to those with mild symptoms and 22.6% greater compared to those with moderate symptoms. These findings suggest that, in cases of greater COVID-19 severity, the deleterious effect of aging on working memory tends to be amplified, potentially leading to more substantial cognitive impairment.

Table 3. Results of Multiple Regression Analyses.

Cognitive Test and Domain	Group	Adj. R^2 (%)	p
DS Forward (Working Memory)	Mild	29	<0.001
	Moderate	31.7	<0.001
	Severe	35.4	<0.001
DS Backwards (Attention/executive control)	Mild	2.7	0.132
	Moderate	33.8	<0.001
	Severe	15.7	<0.001
FAS (Verbal fluence)	Mild	16.4	0.133
	Moderate	31.5	<0.001
	Severe	8.1	<0.014
TEM-R (Recognition memory)	Mild	16.4	0.130
	Moderate	31.5	<0.001
	Severe	8.1	0.014

Adj. R^2 (adjusted R-squared) indicates the proportion of variance explained by the model, corrected for the number of predictors. Higher values reflect greater explanatory power of the model, considering its complexity. DS: Digit Span (Forward Order/Backwards); FAS: Phonemic and Semantic Verbal Fluency; TEM-R: Visual Recognition Memory Test.

For the Digit Span Backward subtest, which measures attention and executive control, a different pattern was observed. The model was statistically significant only for the moderate (Adj. R^2 = 33.8%; $p < 0.001$) and severe groups (Adj. R^2 = 15.7%; $p < 0.001$), but not for the mild group (Adj. R^2 = 2.7%; $p = 0.132$). Age was a negative and significant predictor in the moderate and severe groups, with a stronger effect observed in the moderate group—18.1% higher than in the severe group—suggesting that, for individuals with moderate symptoms, age exerts a proportionally more detrimental role in attentional performance. Educational level once showed no significant effect.

Multiple regression analysis for verbal fluency revealed statistically significant models for the moderate (Adj. R^2 = 31.5%; $p < 0.001$) and severe groups (Adj. R^2 = 8.1%; $p = 0.014$), while for the mild group, the model demonstrated moderate fit (Adj. R^2 = 16.4%; $p = 0.132$) but did not reach global statistical significance. Age was a negative and significant predictor across all severity levels, showing that aging was associated with reduced verbal fluency scores. The effect of age was most pronounced in the moderate group, approximately 63.2% greater than in the severe group and slightly higher than in the mild group (1.5%). These results suggest that, among individuals with moderate symptoms, age plays a particularly relevant role in reducing lexical retrieval ability, possibly reflecting greater executive vulnerability in this subgroup.

However, educational level did not show a significant impact on verbal fluency performance, reinforcing the interpretation that, in this sample, factors such as age and symptom severity played more determinant roles than the cognitive reserve provided by years of schooling.

Regarding performance in the Recognition Memory Test (TEM-R), statistically significant models were found for the moderate (Adj. R^2 = 31.5%; $p < 0.001$) and severe groups (Adj. R^2 = 8.1%; $p = 0.014$), whereas in the mild group (Adj. R^2 = 16.4%; $p = 0.132$), the model did not reach global significance. Age demonstrated a negative and significant effect across all groups, indicating that advancing age was associated with reduced recognition memory scores. This effect was 6.4% greater among individuals with severe symptoms compared to those with mild symptoms and 5.5% greater compared to those with moderate symptoms, highlighting that, in cases of greater disease severity, aging exerts an additionally deleterious effect on memory performance. Figure 1 illustrates the association of age as a predictor of poorer post-COVID cognitive performance.

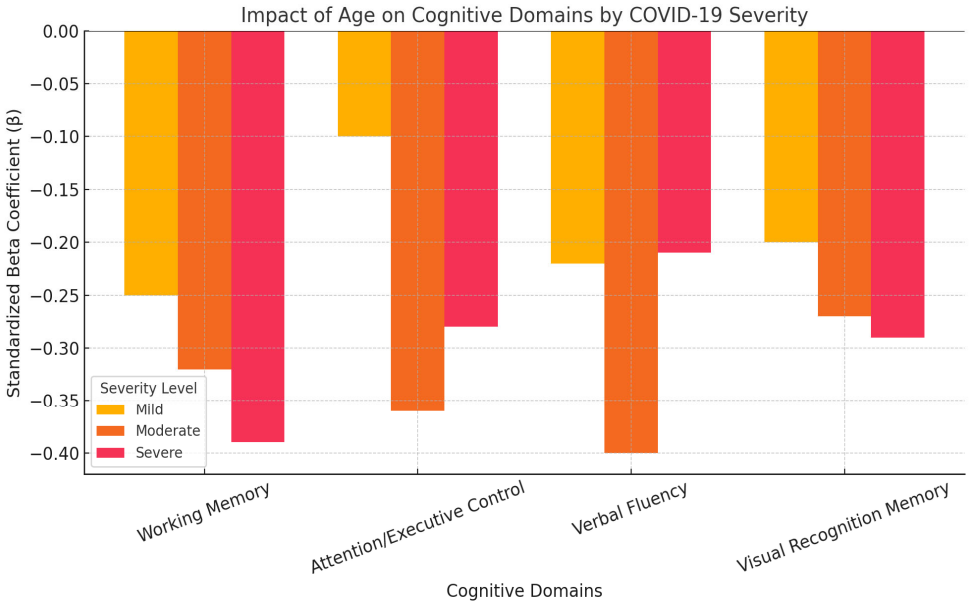

Figure 1. Age as a predictor of post-COVID cognitive performance.

Education level did not prove to be a significant predictor of performance, suggesting that, for recognition memory, the influence of factors such as age and COVID-19 severity outweighs the contribution of cognitive reserves. Overall, the results reinforce that age is a robust predictor of decline in recognition memory in COVID-19 survivors, especially in more severe cases, highlighting the need for targeted neuropsychological monitoring of this population.

4. Discussion

This study reinforces the relevance and complexity of investigations into the impacts of Long COVID, especially considering that participants did not report cognitive complaints prior to infection. Such evidence strengthens the hypothesis that the identified alterations are directly associated with the post-COVID condition, consolidating Long COVID as a phenomenon of high clinical and scientific relevance [1,3–6]. In this sense, it represents one of the greatest contemporary challenges for public health and clinical neuroscience, requiring integrated approaches that include monitoring, rehabilitation, and further investigation of its underlying mechanisms.

Recent evidence indicates that persistent cognitive manifestations associated with post-COVID syndrome represent not only a highly prevalent clinical problem but also an emerging field of urgent scientific inquiry, demanding coordinated efforts to understand the underlying mechanisms and to develop monitoring and intervention strategies [12,15,16,34].

The results of this study provide important evidence that the severity of COVID-19 is associated with a differentiated pattern of cognitive impairment, particularly in domains related to executive functions, attention, working memory, and episodic memory. Overall, as seen in Figure 1, regression models revealed that age was a consistent negative predictor across all tests, especially in groups with moderate and severe symptoms, while educational level did not show a significant impact on any of the evaluated measures.

A detailed analysis by cognitive domain of the information presented in the figure allowed for the identification of important nuances. Working memory (Digit Span Forward) and attention/executive control (Digit Span Backward) were strongly influenced by age, with a more pronounced effect in the severe group for working memory and in the moderate group for attention, at least three years after COVID-19 infection. This result suggests that attentional processes involving cognitive flexibility and inhibitory control may be

particularly vulnerable to interactive effects of aging, neuroinflammatory processes, and post-COVID hypoxia [8,10,18,35,36].

The analysis further revealed that COVID-19 severity was associated with age, amplifying deleterious effects on crucial cognitive functions such as working memory and attention. The more pronounced impact observed in the assessed subtests may be related to neurobiological mechanisms associated with infection, including neuroinflammation, microvascular alterations, and functional impairment in frontoparietal regions and the hippocampus—structures central to executive and memory processing [18,37,38]. Overall, the analyses reinforce that age is a relevant risk factor for post-COVID cognitive impairment, especially in individuals with moderate to severe symptoms, whereas educational level, although recognized as a component of cognitive reserve [38], did not play a significant role in the tested models.

Educational level did not show a statistically significant impact on cognitive performance in any of the Digit Span tasks, indicating that, in this sample, years of schooling were not meaningfully associated with observed variations in cognitive outcomes. A possible explanation for this finding lies in the fact that the sample had, on average, relatively high educational attainment, which may have reduced the variability required to detect significant effects, suggesting a ceiling effect. Moreover, it is plausible that the influence of educational level was attenuated by more robust factors such as age and symptom severity, which exerted greater impact on cognitive performance. Although education is often associated with greater resilience to brain damage, its potential to modulate the cognitive effects of COVID-19 may be limited, especially in the context of a systemic and multifocal insult characteristic of viral infection. This possibility underscores the importance of both preventing the disease and monitoring possible cognitive deficits in individuals who have already been infected, since typically protective personal factors may not be sufficient to mitigate impairments, as suggested by the present findings.

Verbal fluency, which depends on both language networks and executive control, was also impaired in groups with greater symptom severity, consistent with previous findings among disease survivors [38,39]. In this study, verbal fluency showed greater vulnerability in the moderate group, with a more pronounced β coefficient, suggesting that the combination of age and residual COVID-19 dysfunctions significantly affects lexical retrieval ability. This result aligns with studies describing persistent impairments in semantic and phonemic fluency tasks among COVID-19 survivors, even after the acute phase of the disease [22,34,39].

Regarding visual recognition memory, a stronger age-related impact was observed among individuals with severe symptoms, indicating that aging, combined with possible neurobiological insults related to the disease, compromises hippocampal circuits and frontoparietal networks involved in this type of task [37]. This finding supports the hypothesis that severe cases of COVID-19 may potentiate subclinical neurodegenerative processes or accelerate pre-existing trajectories of cognitive decline [40].

This pattern of results is supported by literature indicating that episodic memory—particularly in visual recognition tasks—is sensitive to hippocampal and frontoparietal dysfunctions associated with neuroinflammatory and hypoxic processes triggered by COVID-19 [14,18,25,37]. The more pronounced age effect in individuals with severe symptoms may reflect the combination of biological vulnerability due to aging and pathophysiological mechanisms related to infection, such as persistent inflammation and cerebrovascular alterations.

An important aspect highlighted by this study is that educational level, frequently considered a marker of cognitive reserve [41], did not emerge as a significant protective factor in any of the analyses. This absence of effect may be attributed to two factors: (1) a possible ceiling effect, given the relatively high educational profile of the sample (as

seen in Table 1), reducing the variability needed to detect associations, and (2) the likelihood that the influence of education was attenuated by more robust factors, such as age and symptom severity, which exerted greater impact on cognitive performance. This finding resonates with literature on cognitive reserve, which suggests that individuals with higher education tend to show greater resilience to neurological insults, such as those resulting from inflammatory or hypoxic processes associated with COVID-19 [8,41]. However, our findings suggest that in more severe cases of the disease, the cognitive reserve provided by education may not be sufficient to compensate for the deleterious effects on functions such as working memory and attention.

The observed pattern of lower performance in tasks requiring working memory and executive attention, as seen in Table 2, particularly among participants with severe symptoms, suggests possible dysfunction in prefrontal circuits. The impairment in verbal fluency further supports this hypothesis, corroborating previous neuroimaging findings indicating lesions or alterations in this region associated with similar cognitive impacts [42]. Given the well-established link between executive function deficits, functional capacity, and quality of life [43], the importance of COVID-19 prevention strategies and post-infection care is underscored in order to mitigate additional impairments in these domains.

The observed negative association between IQ and symptom severity three years post-infection indicates that higher cognitive ability may confer some protection against severe outcomes. This could reflect greater health literacy, adherence to preventive behaviors, and more effective management of comorbidities among individuals with higher IQ. Lifestyle factors linked to cognitive function, such as diet, exercise, and stress regulation, may also contribute, and are related to intelligence levels [44]. These results underscore the need to explore how cognitive factors influence long-term health outcomes following infectious diseases.

Regarding associations with age, the findings indicate an amplification of aging effects among individuals with moderate to severe COVID-19. It can therefore be conceptualized that neuroinflammatory processes induced by viral infection may accelerate or intensify damage to brain tissue already vulnerable due to aging. These results highlight the need for preventive and rehabilitative interventions targeted at older populations to reduce disease severity and related cognitive impairments. Preserving cognitive functioning in this population is associated with better quality of life, greater social participation, and reduced healthcare costs, owing to the lower incidence or impact of age-related pathologies [45].

Additionally, the results have relevant implications for planning cognitive rehabilitation strategies, which should consider age as a risk variable not only in isolation but also in relation to the presence or absence of a COVID-19 diagnosis in personal history. The greater impairment observed in association with more severe disease reinforces that a history of severe diagnosis provides more precise prognostic information on the persistence of cognitive deficits, potentially improving intervention planning. These differences in cognitive performance across severity groups corroborate pathophysiological models linking higher systemic inflammatory burden to more extensive neural dysfunction [46,47]. There is thus evidence, grounded in the level of cognitive impact, supporting the implementation of preventive initiatives against COVID-19 worsening once diagnosed in clinical practice.

A noteworthy aspect of this study is the follow-up period adopted—a minimum interval of 36 months. This prolonged observation period, combined with the analysis of multiple cognitive domains, provides evidence for the persistence of deficits that are unlikely to be attributed to transient factors or the acute recovery phase of the disease. When compared with short-term data reported in the literature, this finding positions the present study as a reference point for understanding the evolution and chronicity of cognitive alterations.

Also, these results offer valuable information for designing cognitive rehabilitation strategies in both clinical and public health contexts. By identifying specific cognitive domains of greater vulnerability, it becomes possible to develop evidence-based intervention protocols, particularly focused on the domains most affected in this study (working memory, executive attentional control, selective attention, verbal fluency, and visual recognition memory), with special attention to individuals who experienced moderate or severe forms of the disease.

The evidence from this study strengthens the notion that post-COVID cognitive deficits are multifactorial in nature, resulting from the interaction of neuroinflammatory processes, hypoxia, microvascular alterations, and pre-existing vulnerabilities derived from personal factors such as diagnosis severity, age, and educational level [18,37]. This perspective highlights the importance of longitudinal studies, with the potential to elucidate the progression of these alterations over time, as well as multimodal investigations integrating neuropsychological assessment, neuroimaging, and inflammatory biomarkers.

A relevant contribution of the findings is the stratification of cognitive impairment according to the severity of initial symptoms, observed across different objective measures of cognitive functioning. The presence of deficit differences by severity level allows for a gradient-based interpretation of the relationship between clinical presentation and the expected and persistent functional impairment.

This evidence supports the recommendation of stratified health policies and individualized interventions tailored to diagnostic history, prioritizing more intensive interventions for groups with a history of greater severity and, for them, a more cautious prognostic outlook. Stratification is recommended in future studies, as this structure facilitates interpretations of impact gradients, in contrast to designs that combine the sample regardless of symptom severity, thereby limiting sensitivity to proportional variations in cognitive impairment.

Although the findings of this study contribute significantly to the understanding of COVID-19's cognitive impact, some limitations must be acknowledged. First, the retrospective design does not allow causal relationships to be established nor the temporal trajectory of cognitive impairment to be identified. Another aspect concerns the relatively high educational profile of the sample, which may have limited the variability required to detect the protective effect of education, thereby reducing the generalizability of the results to populations with lower educational attainment. This methodological factor should be considered in interpreting the findings and underscores the importance of future investigations with more heterogeneous samples—especially regarding sociodemographic characteristics—for a broader understanding of the modulatory factors of post-COVID cognitive deficits.

Another major limitation of this study lies in its cross-sectional design, not only retrospective. During three years, a range of factors unrelated to the prior COVID-19 infection may have emerged and contributed to the cognitive findings reported here. Natural aging processes, changes in physical or mental health status, lifestyle modifications, and exposure to new medical or psychosocial stressors could all influence cognitive performance, thereby complicating the interpretation of deficits as direct sequelae of the infection.

Nevertheless, the present findings indicate that greater severity of the prior COVID-19 infection was associated with more pronounced cognitive impairment, reinforcing the plausibility of a causal relationship. This pattern suggests that the disease itself remains a compelling explanatory factor, despite the potential influence of other intervening variables over time. Future research would benefit from adopting designs controlling for aging, comorbidities, and other environmental or health-related variables. Such approaches will be essential to clarify the extent to which cognitive deficits are a direct consequence of COVID-19 and to establish their long-term trajectory.

Another limitation is plausible the reliance on an online-only neuropsychological test battery, which may not provide qualitative observations of examinees' behavior during assessments in order to identify possible biases. Nonetheless, there is growing evidence supporting the reliability and validity of remote and computerized neuropsychological evaluations [48,49], including with patients with and post-COVID-19 [50,51]. Thus, while the format may impose certain restrictions, these are to some extent offset by the enhanced accessibility it offers to participants and the precision of the digital measurements obtained [48]. It is suggested that future research seek comparative validation between the two formats with the public affected by the disease, aiming to assist in the design of other studies.

Finally, despite these potential limitations, it is noteworthy how recognizing risk factors, such as those found between disease severity levels and cognitive deficits, can contribute to strengthening initiatives aimed at promoting preventive or rehabilitative interventions in clinical practice or public policy. An example of this potential contribution could be related to dementia, a condition that, given demographic aging, may particularly encourage initiatives against risk factors or favorable to protective factors [52]. Research has shown a relationship between COVID-19 and delirium [53], a recognized risk factor for dementia [54], and preliminary evidence linking COVID-19 itself to an increased risk of developing this new-onset neurodegenerative condition [55]. Considering that cognitive deficits are also a risk factor for the condition [54], it is suggested that attention be paid to the results found in this study, seeking to manage the severity of COVID-19 symptoms and monitor their persistence to protect against cognitive impairment.

5. Conclusions

From a clinical perspective, the findings of this study highlight the need for long-term neuropsychological monitoring in COVID-19 survivors, particularly those with moderate and severe symptoms and in older individuals. The early identification of cognitive deficits may support the implementation of personalized cognitive rehabilitation programs, focused on the recovery of executive and memory functions, with the goal of reducing the impact of these alterations on autonomy and quality of life.

This study demonstrates that COVID-19 exerts a significant and multifactorial impact on cognition, particularly affecting executive functions, working memory, verbal fluency, and recognition memory. Age and symptom severity emerge as central predictors of these deficits, whereas educational level did not show a relevant protective effect. These findings have direct clinical implications, underscoring the importance of prolonged neuropsychological monitoring and tailored cognitive rehabilitation interventions, especially for older individuals and those who experienced moderate or severe forms of the disease. Thus, this work contributes to advancing knowledge on the cognitive sequelae of COVID-19 and to the development of more effective care strategies for affected populations.

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Data Availability Statement: Restrictions apply to the datasets: The datasets presented in this article are not readily available because the participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research and in order to respect their privacy supporting data is not available.

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Abbreviations

The following abbreviations are used in this manuscript:

AOL	*Atenção On-line* [Online Attention Test]
DS	Digit Span
FAS	Phonemic and Semantic Verbal Fluency Task
IQ	Intelligence Quotient
TEM-R	*Teste de Memória de Reconhecimento* [Recognition Memory Test]
WAIS-III	Wechsler Adult Intelligence Scale, Third Edition
WASI	Wechsler Abreviated Scale of Intelligence

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