Efficacy of dual-task augmented reality rehabilitation in non-hospitalized adults with self-reported long COVID fatigue and cognitive impairment: a pilot study

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Abstract

Background Cognitive impairment and chronic fatigue represent common characteristics of the long COVID syndrome. Different non-pharmacological treatments have been proposed, and physiotherapy has been proposed to improve the symptoms. This study aimed to evaluate the effects of a dual-task augmented reality rehabilitation protocol in people with long COVID fatigue and cognitive impairment.

Methods and materials Ten non-hospitalized adults with reported fatigue and "brain fog" symptoms after COVID (7/10 females, 50 years, range 41–58) who participated in 20 sessions of a 1-h "dual-task" training, were compared to 10 long COVID individuals with similar demographics and symptoms (9/10 females, 56 years, range 43–65), who did not participate to any rehabilitation protocol. Cognitive performance was assessed with the Trail Making Test (TMT-A and -B) and Frontal Assessment Battery (FAB), and cardiovascular and muscular fatigue were assessed with the fatigue severity scale (FSS), six-minute walking test and handgrip endurance. Finally, transcranial magnetic stimulation (TMS) investigated cortical excitability.

Results The mixed-factors analysis of variance found a significant interaction effect only in cognitive performance evaluation, suggesting TMT-B execution time decreased (− 15.9 s, 95% CI 7.6–24.1, $P = 0.001$) and FAB score improved (1.88, 95% CI 2.93–0.82, $P = 0.002$) only in the physiotherapy group. For the remaining outcomes, no interaction effect was found, and most parameters similarly improved in the two groups.

Conclusion The preliminary results from this study suggest that dual-task rehabilitation could be a feasible protocol to support cognitive symptoms recovery after COVID-19 and could be helpful in those individuals suffering from persisting and invalidating symptoms.

Keywords Long haul COVID · NeuroCOVID · Physiotherapy · Executive functions · Cortical excitability

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Introduction

As a possible consequence of the novel coronavirus disease (COVID-19), the presence of symptoms lasting after the resolution of the infection has been commonly reported and known as "long COVID." This clinical entity is usually identified by symptoms persisting more than four to 12 weeks after recovery from COVID-19 infection [1]. Among these symptoms, the most reported are shortness of breath, fatigue, autonomic disorders, headache, and cognitive impairment [2, 3].

"Brain fog" has been defined as minor memory impairments and deficits in focusing [4], mainly involving executive functions such as working memory, attention, parallel processing, planning and problem-solving [5]. Such a clinical picture shares some common features with other syndromes characterized by functional or structural impairment of the frontal and prefrontal lobes, which are crucial hubs for working memory, inhibition, cognitive flexibility, planning, and problem-solving [4]. Despite the pathophysiology of such mechanisms is still debated, neuroinflammation has been hypothesized [6], and brain cortical activity [7], excitability [8, 9], and perfusion and metabolic alterations [10, 11] have been reported. Indeed, hypoperfusion in frontal and temporal lobes investigated in these patients suggests the involvement of attentional and cognitive networks, and motor cortex excitability might reflect such alterations [10].

Reduced physical fitness has been previously reported [12], and a "post-COVID-19 fatigue syndrome" has been suggested, often associated with myalgic encephalomyelitis and "brain fog" [13]. Indeed, transcranial magnetic stimulation (TMS) studies suggest that people with long COVID and brain fog/chronic fatigue might be characterized by altered GABAB- and cholinergic neurotransmission [3, 9]. As such, physiological, cognitive, and neuropsychiatric symptoms have been suggested as predictors of fatigue during long COVID and might share the pathophysiological mechanisms and treatment opportunities [14].

Several therapeutic approaches have been suggested to improve the symptoms of cognitive impairment and chronic fatigue in people with long COVID, including nutraceuticals and supplements [15], hyperbaric oxygen therapy [16], cognitive behavioral therapy [17], and physical therapy [18]. As such, physiotherapy interventions are currently being designed and proposed to improve several long COVID symptoms [19], including fatigue and cognitive impairment, and preliminary research suggests rehabilitation could improve dyspnea, anxiety, kinesiophobia, muscle strength and walking capacity, and quality of life [20]. In particular, virtual and augmented reality could be useful in providing concomitant cognitive and physical training and might be appropriate for people with long COVID [19, 21]. As such, it might be speculated that a dual-task protocol based on augmented reality might be helpful in improving cognitive and physical fitness outcomes, modulating cortical excitability.

The aim of the present study was to evaluate the efficacy of a dual-task rehabilitation protocol on cognitive function, aerobic and strength outcomes, and TMS parameters, in people with long COVID who reported brain fog and cognitive impairments.

Materials and methods

The present prospective observational study was performed between September 2022 and July 2023. The study was approved by the local university ethics committee and was conducted according to the Declaration of Helsinki principles.

Participants were recruited from a University Hospital dedicated neuro-long COVID ambulatory service, with the following inclusion criteria: age between 35 and 65, both sexes, persistent or ex-novo cognitive impairment and fatigue at least after 4 weeks from polymerase chain reaction test–confirmed SARS-CoV-2 infection, who were not hospitalized during the acute phase of the infection. In particular, persistent or ex novo cognitive impairment and fatigue after COVID-19 were self-reported by the participant during a clinical examination with a neurologist, after excluding for potential other causes, as previously described [4, 7, 8]. Exclusion criteria were as follows: previous neurological or psychiatric diseases (i.e., major depressive disorder), neuroimaging assessed major vascular alterations, previous history of cognitive deficits, consumption of agents affecting the nervous system (e.g., antipsychotic, antidepressant or antiepileptic drugs), and reduced mobility/inability to perform physical training due to orthopedic or other clinical conditions (as evaluated by a trained physiotherapist). In addition, we excluded the patients who suffered from moderate-to-severe COVID-19 disease, defined as patients positive for SARS-CoV-2 with clinical and radiographic evidence of lower respiratory tract disease or hospitalized for COVID-19. Participants Montreal Cognitive Assessment (MoCA) scores, considering the appropriate cut-off and corrections [22], were collected by the trained neurologist during the initial visit.

Individuals respecting the inclusion and exclusion criteria were then invited to volunteer for the study and to participate in the dual-task rehabilitation protocol (Dual-Task). Those unable to perform the proposed dual-task protocol due to time constraints and/or excessive distance from the rehabilitation facility, were invited to represent the "control group" (CON) and to perform only the initial and final evaluation. Those participants in the "control group" who reported participating in other studies or rehabilitation/training protocols during the study period were excluded. The Italian version of the International Physical Activity Questionnaire–Short Form (IPAQ-SF) was administered to all the participants at the start and at the end of the study to report physical activity levels and their changes during the study period [23].

Augmented reality dual-task rehabilitation protocol

An augmented reality dual-task rehabilitation protocol was tailored for the long COVID condition based on previous research [24], by proposing a concomitant combination of active exercise and cognitive training. A total of 20 1-h individual sessions were performed twice per week with the support of an augmented reality training system consisting of sensorized platforms and 3-D cameras (Tecnobody, Italy) [21]. Different cognitive tasks were presented to the participants during concomitant active exercises scheduled in

5 graded circuits, as reported in the supplementary material according to the Consensus on Exercise Reporting Template (CERT) for long COVID patients [25], with a more detailed description of the proposed dual-task protocol including warm-up, strengthening exercises, and stretching/relaxation (Suppl 1).

Outcomes assessment

All the assessments were performed during the afternoon to avoid any circadian rhythm bias, within 1 week before the start of the rehabilitation protocol (or control condition), and after 1 week from the end of the rehabilitation protocol (and corresponding period for the control condition).

Cognitive function

The Trail Making Test (TMT) [26] is a neuropsychological evaluation tool consisting of two parts: part A of the test requires joining a series of numbers arranged in various spatial positions on a sheet of paper as quickly as possible; part B requires quickly joining numbers and letters variously arranged on a sheet of paper alternating between the two categories of stimuli. The Frontal Assessment Battery (FAB) [27] is used to determine executive functions and investigates linguistically mediated executive functions, planning, and inhibition, and a score from 0 to 18 (better the score, better the executive functions) is obtained.

Fatigue

The Fatigue Severity Scale (FSS) investigated the burden of fatigue on the daily activities of the subjects [28]: the subjects had to give a rating from 1 to 7 for every item, with 1 representing full disagreement and 7 representing full agreement. The pre-established cut-off was > 4.67. Then, cardiovascular and neuromuscular fatigue were assessed according to previous research on COVID-19 [29]. The six-minute walking test (6MWT) was performed on a 20-m-long indoor hallway, with markers placed at each end of the track [30], asking the participant to walk at the most convenient speed, and the total distance walked at 6 min was recorded. Handgrip strength (HGS) and endurance capacity (HGE) were assessed using a digital handheld dynamometer (Kinvent, Italy). Participants sat on a chair with neutral shoulders, elbows bent at 90°, forearms and wrists in a neutral position. For HGS, participants were instructed to perform a maximum contraction for 3 s in each test. Three measurements with intervals of 30 s were performed, and the higher value was considered in the final analysis [29]. Based on the HGS results, HGE was defined as the longest time the participant was able to maintain handgrip strength at 50% of the maximum; visual feedback was provided by the dynamometer-associated app on a tablet. Also for HGE, three measurements were performed with intervals of 60 s.

Transcranial magnetic stimulation (TMS) protocol

Stimuli were delivered with a stimulating figure-of-eight coil by using a MagProf ® magnetic stimulator (MagVenture Inc., Alpharetta, GA, USA) and an electromyography device (Synergy®, Natus®, Middleton, WI, USA) placed on the first dorsal interosseus. The subjects were instructed to sit in a quiet room in a resting position with their eyes open. The electromyography signals were recorded with a bandpass of 10 to 1000 Hz.

Motor evoked potentials (MEPs) were recorded from the first dorsal interosseus (FDI) muscle of the dominant side with Ag/AgCl surface electrodes attached in a belly–tendon montage. We used a 7-cm figure-of-eight coil, tangentially oriented over the optimum scalp position to elicit MEPs in contralateral FDI, with the induced current flowing in a posterior–anterior direction [31]. Intensities were expressed as a percentage of maximum stimulator output (% MSO). The coil, whose position was continuously monitored during the entire experiment, was placed over the optimal site for eliciting MEPs in the contralateral FDI muscle. The optimal scalp position was determined by moving the coil around the area corresponding to the left M1 (approximately between C3 and P3) in 0.5-cm steps. Then, the optimal scalp position where the stimulation constantly produced the largest MEPs was marked in a tight-fitting plastic swimming cap. For each assessment, peak-to-peak amplitude was measured and averaged offline for each participant. No substantial difference in the latency of the MEPs in all the subjects was recorded.

Resting motor threshold (RMT) was defined as the lowest TMS intensity (expressed in percentage of the maximum stimulator output) that evoked motor potentials (MEPs) of at least 50 μV peak-to-peak amplitude in five of ten successive trials [31]. Paired pulse TMS protocols at different interstimulus interval (ISI) were used to short-interval intracortical inhibition (SICI) at 3 ms and 5 ms ISI and intracortical facilitation (ICF) at ISI 10, 15, and 20 ms [31]. Ten stimuli were delivered for each ISI and protocol in a pseudo-randomized sequence. SICI reflects GABAA receptor–mediated fast inhibitory post-synaptic potentials in corticospinal neurons; ICF reflects glutamatergic signaling [8, 31]. Stimulation intensities were 70% RMT for the conditioning stimulus and 130% RMT for the test stimulus.

Statistics and data analyses

All statistical analyses were performed with SPSS version 23 (IBM). This is the primary analysis of these data. Data are reported as the means, standard deviation, counts and proportions (%) as appropriate. Two-tailed testing was performed. Normality testing using the Shapiro–Wilk test was performed for all datasets. Demographic, anthropometric and clinical characteristics of the two groups were compared with the Mann–Whitney *U* test and Fisher's exact test. Mixed factors analysis of variance (ANOVA) was performed, considering the within-effect (time × 2) and between-effect (groups × 2). For TMS analysis, an addition within-effect (ISI) was included for SICI (ISI × 2) and ICF (ISI × 3). In the case of interaction effects, simple main effects were reported and Bonferroni's correction was applied for the post hoc analyses. Greenhouse–Geisser correction was applied in case of lack of sphericity. The effect size was determined by $p\eta^2$. Significance was set for $p < 0.05$.

Results

Twenty individuals who met the inclusion and exclusion criteria were recruited. None of them reported respiratory problems and no medications were taken during the study period. Ten individuals participated in the dual-task rehabilitation protocol (7/10 females, 50 years, range 41–58, BMI 28.1 ± 7.4 kg/m^2) and 10 participants were included in the CON group (9/10 females, 56 years, range 43–65, BMI 24.3 ± 3.5 kg/m^2), without significant differences in terms of age ($P = 0.060$) sex distribution ($P = 0.263$), and BMI ($P = 0.162$). The demographics and clinical characteristics of the sample are reported in Table 1.

Cognitive function

Concerning cognitive performance, only TMT-B ($F_{1,16} = 6.058$, $P = 0.026$, $p\eta^2 = 0.275$) and FAB ($F_{1,16} = 7.051$, $P = 0.017$, $p\eta^2 = 0.306$) have shown a significant interaction effect between time and group. In particular, TMT-B execution time decreased (− 15.9 s, 95% CI 7.6–24.1, $P = 0.001$) and FAB score improved (1.9, 95% CI 0.8–2.9, $P = 0.002$) only in the dual-task group (Fig. 1). TMT-A presented a significant time effect ($F_{1,16} = 40.577$, $P < 0.001$, $p\eta^2 = 0.717$), suggesting TMT-A execution time decreased significantly by 8.9 s (95% CI − 11.81 to − 5.91,

Table 1 Demographic, anthropometrics and clinical characteristics in the dual task (*n*=10) and control (*n*=10) group. Medians (25th-75th percentile)

	Dual Task *n* = 10	**CON** *n* = 10	**Significance**
Age (y)	50 (41–58)	56 (43–65)	0.060
Sex−females [*n* (%)]	7 (70)	9 (90)	0.263
BMI (kg/m^2)	26.4 (23.6–30.5)	23.3 (21.8–27.3)	0.162
Time from SARS-CoV-2 infection (wk)	23 (21–27)	22 (20–26)	0.503
MoCA at the visit (correct score)	24.8 (24.2–26.9)	25.7 (24.5–26.9)	0.961

Dual-Task dual-task rehabilitation group; *CON* control group; *BMI* body mass index; *SARS-CoV-2* severe acute respiratory syndrome coronavirus; *MoCA* Montreal Cognitive Assessment. Bold values for *p* < 0.05 at the Mann-Whitney U-Test and Fisher's Exact test

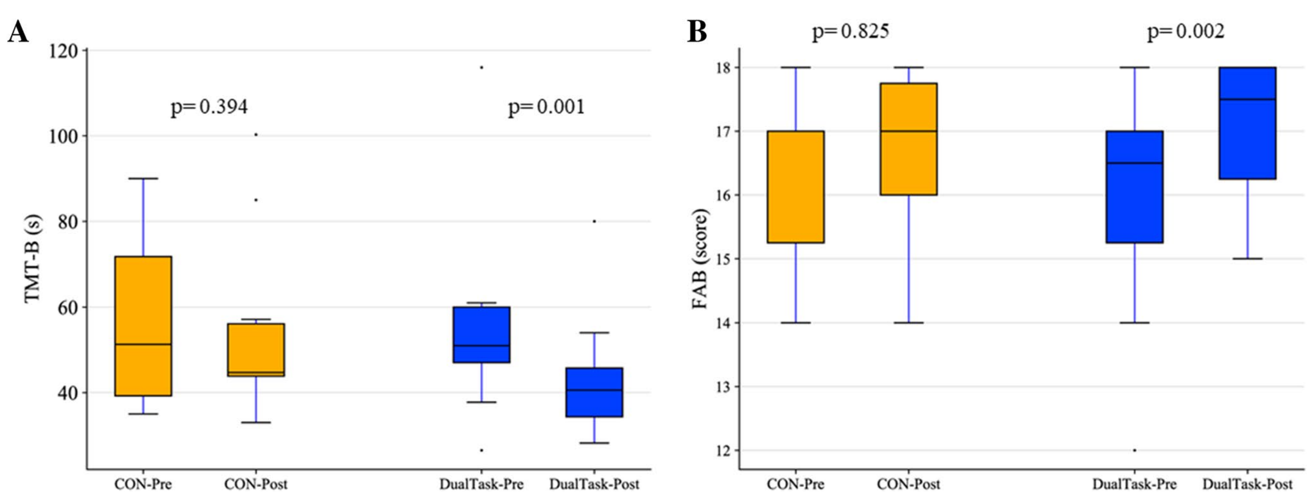

Fig. 1 Box plots representing the difference before and after the protocol in the **A** trail making test B (TMT-B, s) and **B** frontal assessment battery (FAB, score), in the control group (*n* = 10, orange) and dual-task group (*n* = 10, blue). Significance for time is the simple main effect at the mixed-factors analysis of variance

$P < 0.001$) independently from the group. Cognitive function outcomes are reported in Table 2.

Fatigue

Regarding cardiovascular and neuromuscular fatigue parameters, no significant interaction was reported. Only FSS showed a significant time effect ($F_{1,16} = 12.654$, $P = 0.003$, $p\eta^2 = 0.442$). No significant interaction or time effects were reported for any of the handgrip measures, although a significant group effect was found in HGE ($F_{1,11} = 5.683$, $P = 0.036$, $p\eta^2 = 0.341$), with the dual-task group being characterized by higher endurance values (28.5 s, 95% CI 2.2–54.9, $p = 0.036$). No significant effects were reported for 6MWT and no significant effects were found for the IPAQ-SF. Cardiovascular and neuromuscular fatigue outcomes are reported in Table 2.

TMS

TMS-derived outcomes are reported in Table 3.

SICI

No significant interaction effect between ISI, time, and group were found ($F_{1,18} = 0.646$, $P = 0.432$, $p\eta^2 = 0.035$). In addition, no significant interaction effect between time and group ($F_{1,18} = 0.651$, $P = 0.430$, $p\eta^2 = 0.035$), ISI and group ($F_{1,18} = 0.427$, $P = 0.522$, $p\eta^2 = 0.023$), and ISI and time were found ($F_{1,18} = 0.630$, $P = 0.438$, $p\eta^2 = 0.034$). Finally, none of the main effects results were significant, ISI ($F_{1,18} = 1.941$, $P = 0.181$, $p\eta^2 = 0.097$), time ($F_{1,18} = 1.305$, $P = 0.268$, $p\eta^2 = 0.068$), and group ($F_{1,18} = 0.323$, $P = 0.577$, $p\eta^2 = 0.018$).

Table 2 Cognitive functions, physical activity behavior, and fatigue in the dual task (*n*=10) and control (*n*=10) group. Medians (25th-75th percentile)

	Dual-Task *n* = 10	**CON** *N* = 10	**Significance** *Time x Group*
TMT-A (s)			
pre	30.0 (28.0–33.2)	33.4 (26.1–46.0)	0.153
post	24.6 (17.1–27.3) †	27.4 (21.1–31.2) †	
TMT-B (s)			**0.026**
pre	51.0 (47.0–60.0)	51.3 (39.3–71.8)	
post	40.6 (34.3–45.7) ‡	44.7 (43.9–56.1)	
FAB (score)			**0.017**
pre	16.5 (15.3–17.0)	17.0 (15.3–17.0)	
post	17.5 (16.3–18.0) ‡	17.0 (16.0–17.8)	
FSS (score)			0.097
pre	6.06 (4.50–6.59)	4.83 (3.17–6.11)	
post	4.05 (3.08–4.83) ‡	4.17 (2.25–5.70) †	
IPAQ-SF (MET)			0.615
pre	2310 (488–3870)	1155 (953–3345)	
post	1335 (668–2430)	1785 (1373–2087)	
6MWT (s)			0.156
pre	520 (375–607)	575 (510–671)	
post	615 (555–630)	566 (545–620)	
HGS (kg)			0.848
pre	21.9 (18.6–25.5)	16.2 (12.0–19.2)	
post	22.2 (19.0–25.3)	14.0 (12.7–18.7)	
HGE (s)			0.187
pre	113 (72–150)	65 (44–75) *	
post	77 (66–92)	59 (54–75) *	

Dual-Task dual-task rehabilitation group; *CON* control group; *TMT* trail making test; *FAB* frontal assessment battery; *FSS* fatigue severity scale; *IPAQ-SF* international physical activity questionnaire short form; *6MWT* six minutes walking test; *HGS* maximum handgrip strength, and *HGE* handgrip endurance at 50%max, for the dominant limb. Bold values for $p < 0.05$ at the mixed-factors ANOVA interaction (time; group). *Significant main effect: group. †Significant main effect: time. ‡Significant simple main effect: time

Table 3 TMS parameters in the dual task (n=10) and control (n = 10) group. Medians (25th-75th percentile)

	Dual-Task *n* = 10	CON *N* = 10	Significance *Time x Group*
RMT (% SO)			0.066
pre	65 (55−69)	66 (59−71)	
post	82 (66−99)	71 (56−80)	
SICI (% of unconditioned stimulus)			0.268
3ms			
pre	19 (8−33)	17 (10−23)	
post	11 (2 -85)	42 (22−55)	
5ms			
pre	39 (15−64)	33 (18−50)	
post	19 (3−28)	52 (12−100)	
ICF (% of unconditioned stimulus)			0.723
10ms			
pre	89 (77−131)	92 (42−183)	
post	100 (52−167)	93 (51−144)	
15ms			
pre	83 (52−146)	100 (58−100)	
post	183 (106−275)	148 (108−270)	
20ms			
pre	116 (46−169)	100 (50−146)	
post	100 (100−237)	75 (35−142)	

Dual-Task dual-task rehabilitation group; *CON* control group; *RMT* resting motor threshold; *SICI* short intracortical inhibition; *ICF* intracortical facilitation. Bold values for $p < 0.05$ at the mixed-factors ANOVA interaction (time; group)

ICF

No significant interaction effect between ISI, time, and group were found ($F_{1,18} = 0.828$, $P = 0.445$, $p\eta^2 = 0.044$). Furthermore, no significant interaction effect between time and group ($F_{1,18} = 0.129$, $P = 0.723$, $p\eta^2 = 0.007$), ISI and group ($F_{2,36} = 1.163$, $P = 0.324$, $p\eta^2 = 0.061$), and ISI and time were found ($F_{1,18} = 0.636$, $P = 0.535$, $p\eta^2 = 0.034$).

As regard the main effects ISI and group, both were found not significant ($F_{2,36} = 0.731$, $P = 0.489$, $p\eta^2 = 0.039$) ($F_{1,18} = 0.039$, $P = 0.845$, $p\eta^2 = 0.002$), whereas a tendency towards a significance for the time effect was found ($F_{1,18} = 4.088$, $P = 0.058$, $p\eta^2 = 0.185$); in particular, MEP increased by 70% (95% CI 3–150, $P = 0.058$) independently from the group.

Discussion

Cognitive impairment and chronic fatigue can be common characteristics of people suffering from long COVID syndrome. Several pharmacological and non-pharmacological approaches have been recommended and implemented, however. The effects of such interventions are still being evaluated and debated [32]. The results from this study suggest that a dual-task rehabilitation protocol supported by augmented reality visual feedback could help the recovery of executive functions impairment. Indeed, the main finding consists of a significant interaction effect of the TMT-B and FAB evaluations, suggesting that despite the executive functions can improve as time passes from the infection and the presence of long COVID symptoms, the proposed dual-task protocol can enhance cognitive functions' recovery. In contrast, the recovery of cardiovascular and neuromuscular fatigue was spontaneous and seems not to be influenced by the rehabilitation protocol. Finally, altered cortical excitability seems to slightly change in the study period, with a tendency towards an improvement of the ICF in both groups.

Despite TMT could be not sufficient to detect mild "brain fog" conditions, as well as other tests used to evaluate Alzheimer's diseases and other types of cognitive impairment, it has been used in long COVID syndrome, including studies on the effects of different treatments [33]. TMT-B has been found to distinguish between individuals who suffered from mild disease and those who required intensive care hospitalization [33]. TMT-A is a measure of attention/processing speed, and TMT-B reflects executive function, the latter being reported as most impaired [34]. Also, FAB has been evaluated in people with long COVID and "brain fog," presenting worse scores compared to healthy controls [9]. As reported in a recent meta-analysis, combined physical and cognitive training has been suggested to better improve executive functions in older adults, without compromising physical efficacy, and exergames could provide additional benefits [35]. The results from the present study are in line with previous research, as we found a larger improvement in executive functions outcomes in long COVID individuals who participated in the dual-task protocol.

The 6MWT has been suggested to report physical function in COVID-19 survivors, especially to evaluate cardiopulmonary exercise capacity [36]; similarly, handgrip strength has been used to assess neuromuscular function [37], also in relation to cardiovascular health status. In terms of such alterations, contrasting results can be found, as in non-hospitalized adults with post-acute COVID-19 syndrome, handgrip strength was not found significantly reduced compared to the healthy controls [38]. To the best of the authors' knowledge, no study has been published evaluating the effects of physiotherapy to restore cardiopulmonary or neuromuscular capacity in non-hospitalized long COVID individuals, whereas the effects of nutritional interventions have been reported. A previous study has suggested that a multicomponent nutritional supplement might help improve functional recovery in adults suffering from chronic fatigue after COVID-19 [39]. Similarly, a combination of 1.66 g l-arginine plus 500 mg liposomal vitamin C significantly improved the 6MWT and handgrip strength [40]. In this study, the dual-task rehabilitation protocol did not result in a superior improvement of the 6MWT or handgrip strength and endurance, compared to the control condition. However, it should be noted that most of the participants did not present severe impairments in these outcomes prior to the intervention, and that the dual-task intervention was not focused on cardiorespiratory or strength training.

TMS evaluation has been proposed in people with long COVID and "brain fog"/fatigue, suggesting altered cortical excitability [8, 9]. Intracortical GABAergic, cholinergic, and glutamatergic dysfunctions have been reported [8, 9], as well as changes in electroencephalographic activity, brain perfusion, and metabolism [7, 10, 11]. Results from this study are in line with previous research, suggesting people with long COVID and "brain fog" might be characterized by impaired gamma-aminobutyric acid-B (GABAb)activity, suggestive of impaired intracortical facilitation [8]. In this study, the dual-task protocol did not result in any change in the TMS-associated parameters, although a tendency towards a time-dependent improvement was observed, as an increase in GABAb-mediated MEP was observed.

Different pathophysiological mechanisms have been debated as potential causes of the variety of long COVID symptoms; in terms of neurological and muscular manifestations, inflammation, immune response, and vascular and small fibers damage have been hypothesized [41]. Therefore, physical activity and nutrition should be recommended and implemented in those individuals manifesting long COVID symptoms.

In summary, this study provides preliminary evidence of the efficacy of a dual-task physiotherapy protocol to improve cognitive functions in people with long COVID "brain fog." Several rehabilitation protocols have been suggested and are still being evaluated, whereas other kinds of interventions, and in particular nutritional/nutraceutical support, have been found to help the long COVID symptoms recovery.

Study Limitations

Despite the promising result from the present study, the sample size was moderate, and all the participants were not hospitalized/did not suffer from severe symptoms during the acute phase of the infection. Indeed, despite a subjective reporting of both cognitive impairment and fatigue, only a few of them presented outcomes below the commonly accepted cut-off values for pathological conditions. As such, for most of the assessed variables no significant differences were observed in the 2 months of the study protocol, with a larger improvement only in the cognitive outcomes of those participating in the dual-task exercises. Therefore, it might be speculated the proposed rehabilitation protocol might have provided additional efficacy in individuals characterized by worse physical capacity; since its safety and the advantages provided by the augmented reality support, it was well-accepted by the participants, with good participation in the exercise sessions; hence, it could be proposed to long COVID individuals reporting more severe cognitive impairment and fatigue symptoms. In addition, the groups were not randomized and participation to the dual-task protocol was based on participants' preference; this might have affected the results as it might be possible that only those with fewer limitations or with higher therapeutic compliance and motivation participated in the experimental protocol, therefore influencing some of the observed differences in the reported outcomes, especially regarding executive functions.

Conclusions

Long COVID symptoms, including cognitive deficits and fatigue, can be common and often represent a major limitation to people's quality of life and independence. Physical activity and rehabilitation protocols are encouraged, despite few studies that have evaluated the efficacy of different exercise protocols. The preliminary results from this study suggested that an augmented reality dual-task protocol, combining active exercises and cognitive tasks, could improve cognitive functions, whereas most of the fatigue-related parameters did not present significant differences compared to the control group. The proposed protocol was safe and well-accepted, and the augmented reality feedback could promote adherence to the exercise sessions, representing a feasible physiotherapy approach for people with long COVID.

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Data availability Anonymized data can be requested upon reasonable request to the corresponding author.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval All the participants and their legal guardians were requested to sign an informed consent. All procedures were approved by the ethical committee of the Comitato Etico Unico Regionale del Friuli-Venezia Giulia.

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