The Impact of Brief, Rapid Onset COVID-19 on Executive Functions in Maltese Working-Age Adults

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A dissertation presented to the Department of Psychology, Faculty for Social Wellbeing in partial fulfilment of the requirements for the degree of Master of Psychology in Neuropsychology at the University of Malta

May, 2025

L-Università ta' Malta

FACULTY/~~INSTITUTE/CENTRE/SCHOOL~~ for Social Wellbeing

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Abstract

Executive functioning (EF) is the ability to respond effectively to novel or changing conditions while maintaining emotional, cognitive, and social functioning. Emerging evidence suggests that even mild COVID-19 may impair EF domains such as inhibition, planning, and cognitive flexibility, yet few studies have explored this in non-hospitalised populations. The present study investigated the EF performance of working-age adults in Malta who had experienced mild/moderate COVID-19. A quantitative design was utilised, comparing individuals who previously tested positive for COVID-19, referred to as the COVID-19 group (n = 27) with those who had never tested positive, the NON-COVID-19 group (n = 43). Participants completed a demographic questionnaire as well as four performance-based neuropsychological assessments—Colour-Word Interference Test (CWIT), Trail Making Test (TMT), Zoo Map Test, and Rule Shift Cards (RSC)—and were assessed on key EF domains. No significant group differences were found across most EF measures. Both groups performed similarly in inhibition, planning, and task-switching. A single statistically significant result was found on the Rule Shift Cards test, with the COVID-19 group outperforming the non-COVID-19 group (p = .021). This result may reflect limitations in test sensitivity or the influence of psychological factors such as anxiety and motivation. As the first study to investigate this topic within a Maltese sample, the findings provide preliminary insight into post-COVID executive functioning. Nonetheless, methodological constraints warrant cautious interpretation. Future research should incorporate a broader range of performance-based and self-report EF measures, alongside longitudinal and ecologically valid designs, to better capture potential cognitive effects.

Keywords: Executive Functioning, COVID-19, Neuropsychological Assessment, Cognitive Functioning

To those whose lives have been altered by the lingering effects of COVID-19, in the hope that this study may inspire further research and better understanding.

Acknowledgements

First, I would like to express my sincere gratitude to my supervisors, Dr Kristina Bettenzana and Dr Fiona Ambery, for their expert guidance, thoughtful feedback, and ongoing support throughout this research journey. Your encouragement and insight have been deeply appreciated.

To my parents, Doreen and Joseph — thank you for always encouraging me to follow my dreams, no matter how challenging the path. Your endless patience, belief in me, and unwavering support have carried me through every step of this process. To my brothers and their families — your kindness and encouragement have meant more than words can express.

I would also like to mention my dogs, Sophie and Chucky Joy, whose calm presence and companionship grounded me when I needed it most.

To my course colleagues, Luana, Tereza, and Aurora — your encouragement, wisdom, and shared perseverance made this journey not only possible, but meaningful. I am truly grateful to have walked this path alongside you.

To my friends — too many to name — thank you for always offering a listening ear, kind words, and motivation during the most intense phases of this project. Your support, in and out of academic life, meant more than you know.

Finally, my heartfelt thanks go to all the participants who contributed their time and experiences to this research. Your involvement made this study possible.

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List of abbreviations

EF – Executive Functioning

D-KEFS - Delis-Kaplan Executive Function System

BADS - Behavioural Assessment of the Dysexecutive Syndrome

TMT – Trail Making Test

CWIT – Colour-Word Interference Test

ZM – Zoo Map Test

RCS – Rule Card Shift

PFC – Prefrontal Cortex

CPT – Continuous Performance Test

WCST – Wisconsin Card Sorting Test

M-WCST – Modified Wisconsin Card Sorting Test

Chapter 1: Introduction

Preamble

This introduction chapter describes the purpose and objectives of the study, which investigated the effects of COVID-19 on executive functioning (EF) in Maltese working-age adults. A definition of EF will be presented, followed by background information on how COVID-19 may impact executive functioning, as well as a review of current research in this area. The chapter will then outline the study's methodological approach, rationale, and its anticipated research and clinical contributions. Finally, an overview of each chapter in the dissertation will be provided.

Executive Functioning

EF are cognitive processes required for adaptive and goal-directed behaviour. According to Lezak et al. (2012), EF is the ability to respond effectively to novel or changing conditions while maintaining emotional, cognitive, and social functioning. Despite its widespread use, EF remains an ambiguous concept, with researchers debating whether it is homogeneous or formed of distinct components (Diamond, 2013; Miyake et al., 2000). This study uses Lezak's function-oriented definition because of its therapeutic relevance and emphasis on real-world adaptability.

Several theoretical models have been proposed to explain the mechanisms underlying EF. Norman and Shallice (1986), for example, conceptualised the *Supervisory Attentional System* (SAS), a model that differentiates between automatic and controlled processes and is especially relevant in situations requiring inhibition, planning, or problem-solving. This aligns with Lezak's definition by emphasising goal-directed behaviour in unpredictable situations. More recent frameworks, such as Miyake et al.'s (2000) model, categorise EF into core components like inhibition, cognitive flexibility, and working memory.

Cognitive flexibility is the ability to transition between tasks while adapting to changing circumstances (Braem & Egner, 2018). It is regarded as a dynamic feature of the cognitive system, resulting from interactions between cognitive and sensorimotor mechanisms (Ionescu, 2012). Rodríguez-Nieto et al. (2022) define inhibition as the suppression of inappropriate reactions. This executive process is critical to tasks that require self-control and reaction monitoring. Similarly, Chambers et al. (2009) emphasized that response inhibition is crucial for successful cognitive control and plays a role in response selection, working memory, and attention.

Another aspect of EF is planning, a higher-order executive activity that requires mentally organising and scheduling steps before carrying them out. It relies on attention, memory, and impulse control to make suitable choices (Diamond, 2013; Lezak et al., 2012). Disruptions to executive functioning—whether developmental, neurological, or environmental—can lead to significant and long-term consequences, including dementia, executive dysfunction (such as disinhibition and apathy), and attention-deficit/hyperactivity disorder (ADHD) (Girotti et al., 2018; Jobson et al., 2021; Sadozai et al., 2024). Dysexecutive syndrome, as defined by Poletti et al. (2016), involves emotional, motivational, behavioural, and cognitive deficits, typically associated with frontal lobe injury. Given these implications, EF remains a central focus in neuropsychological research and clinical evaluation.

An area in the brain responsible for EF is the prefrontal cortex (PFC), which plays a key role in functions such as working memory, planning, cognitive flexibility, and decision-making (Domenech & Koechlin, 2015; Roberts et al., 1998; Yuan & Raz, 2014). It regulates goal-directed behaviour through top-down control and interacts with neurotransmitters like dopamine and serotonin (Jones & Graff-Radford, 2021; Kehagia et al., 2010). This cortex

continues to develop until early adulthood, which means that it is particularly vulnerable, as discussed by Chini and Hanganu-Opatz (2020).

The Impact of COVID-19 on Cognitive Functioning

SARS-CoV-2, the virus that causes the COVID-19 infection, may reach the brain through two main routes: crossing biological barriers, such as the blood–brain barrier (BBB) or blood–cerebrospinal fluid barrier (Kabbani & Olds, 2020), or via direct nerve invasion (Sun et al., 2024). Neuroinvasion through the olfactory nerve has been widely proposed due to its anatomical connection to brain regions involved in olfactory processing (Sun et al., 2024), and viral particles have been detected in cerebrospinal fluid and frontal lobe tissue (Moriguchi et al., 2020; Paniz-Mondolfi et al., 2020). Following its entry into the central nervous system, SARS-CoV-2 has been shown to impair brain function through several biological mechanisms (Douaud et al., 2022). One such mechanism is neuroinflammation, which is triggered as part of the body's immune response to the virus (Tay et al., 2020).

Cognitive impairments are often referred to as part of the “brain fog” phenomenon and are commonly reported in patients with post-acute sequelae of SARS-CoV-2 infection (PASC) or "Long COVID" (Wang et al., 2024). Imaging studies have shown reduced grey matter in the frontal and temporal lobes, as well as disruptions in functional connectivity in regions associated with executive functioning (Nasir et al., 2025), suggesting a potential structural basis for these cognitive difficulties.

Memory, concentration, processing speed, and language fluency (i.e. difficulty locating words) are among the most commonly reported symptoms, as researched by Guo et al. (2022) and James et al. (2025). These symptoms have been documented across all age groups and may persist for several months (Greenhalgh et al., 2024). Cognitive changes have been proven to interfere with daily functioning, including work and academic performance as well as overall quality of life. Miller et al. (2025) argue that cognitive difficulties from Long

COVID result not just from physical brain changes, but also from a vicious cycle of social withdrawal, unemployment, and lower activity levels. These variables contribute to psychological distress, which in turn exacerbates cognitive impairment.

Current Research on Executive Functioning Following COVID-19

Although research has identified cognitive deficits in individuals with COVID-19, most studies focus on severe cases involving hypoxia or neuroinflammation (Aderinto et al., 2025; Chen et al., 2025). Consequently, less is known about the impact of mild infections on executive functioning, especially among non-hospitalised individuals, despite growing evidence of their vulnerability.

For example, Lajim et al. (2024) found that 44% of patients exhibited cognitive impairment three months after mild COVID-19 infection, with similar rates persisting at six months. These impairments included deficits in attention control, planning, and cognitive flexibility, core components of executive functioning. Becker et al. (2021) discovered that post-COVID individuals had persistent abnormalities in attention and executive control several months after infection. Similarly, Hampshire et al. (2021) conducted a large-scale online cognitive assessment and found impairments in reasoning, problem solving, and cognitive flexibility among recovered COVID-19 patients.

Rationale for the Study

While some local studies (e.g., Cuschieri, 2021a, 2021b) have examined the broader long-term health impacts of COVID-19, including mental health and general wellbeing, none have specifically addressed how acute infection affects executive functioning or specific cognitive processes. As highlighted earlier, executive functions appear to be particularly vulnerable to disruption following COVID-19, even in individuals who experienced mild symptoms.

The present study aimed to assess executive function performance in individuals who previously contracted COVID-19, in comparison to those who have not. As such, the use of ecologically valid tests in this study aimed to provide a more accurate reflection of executive functioning as it occurs in everyday life (Burgess et al., 2006).

The investigation focused on the following primary research questions:

- How does COVID-19 affect executive functioning in working-age adults in Malta?

- What is the difference in performance on executive functioning tests between individuals who experienced acute COVID-19 with those who never tested positive for the infection?

The following is the secondary hypothesis:

- H_1: Individuals who experienced COVID-19 will show significantly lower performance on EF subtests compared to individuals who tested negative for COVID-19.

To investigate the primary research questions and test the proposed hypotheses, a quantitative research approach was used to obtain a larger and generalisable sample. Convenience sampling, which is a non-probability sampling method, was selected, whereby any eligible and interested candidates were invited to take part in this study. Inclusion criteria required participants to be Maltese citizens between the ages of 18-64 with sufficient proficiency in English to understand and complete the assessment materials. The aims of the study were investigated through standardised performance-based neuropsychological measures of EF. Additionally, a demographic questionnaire was administered to explore any possible associations related to variables such as gender, age and the number of years since completion of highest level of education. 70 participants were recruited for this study, each of whom completed a demographic questionnaire as well as four subtests of EF.

Overview of Chapters

Chapter one introduced the research topic by providing a general background and summarising key literature related to the main research questions. Chapter two will offer a more in-depth review of the existing literature on executive functioning and COVID-19. Chapter three outlines the methodological approach, including the participant selection criteria, sample characteristics, data collection tools, hypotheses, and the chosen statistical tests. The fourth chapter will present the study's findings, with a focus on any identified associations between variables. Chapter five presents a discussion of the findings in light of previous studies. Finally, Chapter six will conclude the dissertation by describing the key findings, addressing the study's strengths and limitations, while offering recommendations for future research.

Chapter 2: Literature Review

Introduction

The COVID-19 pandemic has brought increased attention to its potential long-term impact on cognitive functioning. Executive functioning (EF), in particular, has emerged as a key domain affected by the virus. The chapter begins by outlining the neurological mechanisms through which COVID-19 may affect cognition, followed by a review of key theoretical models and assessment approaches to EF. Finally, it evaluates empirical findings

on EF outcomes post-COVID, with a focus on identifying methodological limitations and gaps relevant to the current investigation.

COVID-19

COVID-19 is an issue that has received a lot of attention in recent years—a global health emergency that has not only harmed physical health but additionally raised worries about its possible neurological and cognitive repercussions, particularly in terms of executive function. The purpose of this study is to evaluate these cognitive consequences by comparing individuals with and without a history of COVID-19.

Overview of the pandemic

The virus was first discovered in Wuhan, China, with authorities alerting World Health Organization (WHO) authorities about cases of 'viral pneumonia' (WHO, 2022). This virus quickly spread throughout the world, leading WHO to declare a Public Health Emergency of International Concern (PHEIC) on the 30th of January 2020 and proceed to characterising it as a pandemic on the 11th of March, 2020 (WHO, 2025).

Infected patients range in age from infants to the elderly, and the virus causes a variety of clinical symptoms. COVID-19 severity, which will be discussed later in this review, ranges from asymptomatic or mild cases to severe and life-threatening infections necessitating hospitalisation and procedures such as intubation after respiratory collapse (Baj et al., 2020). Until 19th December 2023, there had been 120,767 confirmed cases of the virus in Malta since the outbreak, according to WHO (2023b).

The infection mechanism

According to the WHO (2023a), Coronavirus Disease (COVID-19) is an infectious illness caused by the SARS-CoV-2 virus. While it primarily affects the respiratory system, research has increasingly linked the virus to multi-organ involvement, including the central

nervous system (CNS) (Hoffmann et al., 2020). Entry into the CNS is of particular interest due to its potential to trigger neurological symptoms such as headache, brain fog, memory issues, and executive dysfunction (Stein et al., 2022). Understanding the mechanisms through which SARS-CoV-2 spreads in the body is important for contextualising its possible effects on cognitive domains.

Entry via the Respiratory System. SARS-CoV-2 primarily enters the body through the respiratory tract, where its spike protein binds to angiotensin-converting enzyme 2 (ACE2) receptors on epithelial cells. This process is facilitated by TMPRSS2, an enzyme that enables cellular entry (Nishiga et al., 2020). Although the lungs are the primary site of infection, ACE2 is also expressed in other organs, including the heart, kidneys, and vasculature, allowing the virus to spread systemically—particularly in individuals with comorbidities such as cardiovascular disease, diabetes, or hypertension (Clerkin et al., 2020; Madjid et al., 2020). These pre-existing conditions are associated with more severe illness and increased risk of complications (Grasselli et al., 2020; Huang et al., 2020; Wang et al., 2020).

Neurological Involvement and CNS Entry. Although SARS-CoV-2 primarily infects the respiratory system, increasing evidence suggests it can access the central nervous system (CNS), potentially contributing to neurological symptoms. Entry into the CNS may occur via two primary mechanisms: direct invasion across protective barriers such as the blood–brain barrier (BBB) or blood–cerebrospinal fluid barrier (B-CSF-B), and neuronal spread via cranial nerves (Sun et al., 2024). ACE2 receptors, found in brain tissue, may facilitate BBB penetration (Kabbani & Olds, 2020), and clinical symptoms such as encephalopathy and altered consciousness support this theory (Helms et al., 2020).

Viral RNA has been identified in postmortem brain and cerebrospinal fluid samples, suggesting potential neurotropism (Moriguchi et al., 2020; Paniz-Mondolfi et al., 2020).

Though some researchers propose additional neural routes—such as via the olfactory, vagus, or glossopharyngeal nerves (Vitale-Cross et al., 2022; Xu et al., 2021)—this remains a topic of debate. For instance, recent autopsy studies suggest protective structures may limit direct neural invasion (Khan et al., 2022). Thus, while neuroinvasion is biologically plausible, further research is needed to clarify the extent and mechanisms of CNS entry.

Pathophysiological impact on the brain

SARS-CoV-2 may disrupt brain function through a variety of biological mechanisms once it enters the central nervous system (Erickson et al., 2021). The sections that follow will go into greater detail about these pathways, illustrating how they may contribute to the neurological alterations seen in affected individuals.

Neuroinflammation. One of the most frequently proposed mechanisms for COVID-19–related cognitive disturbance is neuroinflammation. SARS-CoV-2 infection can produce a systemic immune response, characterised by the release of pro-inflammatory cytokines such as interleukin-6 (IL-6) and tumour necrosis factor-alpha (TNF-α) (Huang et al., 2020; Tay et al., 2020). These cytokines can disrupt the integrity of the blood–brain barrier (BBB), allowing peripheral immune cells and inflammatory mediators to enter the central nervous system (Engelhardt & Coisne, 2011; Erickson et al., 2021). This process has been implicated in the onset of neuroinflammation, which in turn has been associated with cognitive symptoms such as brain fog, fatigue, attentional dysregulation, and memory difficulties.

While the most severe inflammatory effects have been reported in hospitalised or critically ill patients, emerging evidence suggests that even mild cases may result in subclinical neuroinflammatory changes. Erickson et al. (2021) argue that low-grade inflammation may disrupt functional connectivity within key cognitive networks. Similarly, Grant et al. (2020) suggest that febrile responses—common even in mild infection—can

activate inflammatory pathways in brain regions responsible for executive control and attentional processing. However, these studies primarily rely on correlative evidence, and further research using neuroimaging or cerebrospinal fluid biomarkers is needed to confirm these associations in non-hospitalised populations.

Hypoxia-Related Brain Injury. Another mechanism through which COVID-19 may affect cognition is hypoxia. Hypoxia, defined as a reduction in oxygen availability, has been widely reported in COVID-19 patients, including those without overt respiratory symptoms—a phenomenon referred to as "silent hypoxaemia" (Vitale-Cross et al., 2022). This condition is a recognised predictor of disease severity and has been linked to long-term neurocognitive outcomes (Kashani, 2020; Rello et al., 2020).

Hypoxia may impair the BBB and increase its permeability, enabling the infiltration of neurotoxic compounds (Yang & Rosenberg, 2011). Moreover, it activates hypoxia-inducible factor-1 (HIF-1), which—although initially neuroprotective—can exacerbate oxidative stress and lead to neuronal injury if dysregulated (Goto et al., 2014; Semenza, 2011). These effects may particularly impact the prefrontal cortex and hippocampus—regions heavily implicated in executive functioning, working memory, and attentional regulation (Wang et al., 2021). Notably, while most research on hypoxia and cognition has focused on severe or hospitalised cohorts, it remains unclear whether these processes manifest to a measurable degree in younger or non-hospitalised individuals.

Disruption of Neurotransmitter Systems. Neuroinflammation may also disrupt neurotransmitter regulation, particularly involving serotonin, dopamine, and glutamate—systems integral to attention, behavioural inhibition, and cognitive flexibility (Alnefeesi et al., 2020; Raza et al., 2024). These cytokine-induced changes can impair prefrontal cortical functioning, contributing to cognitive and affective symptoms observed post-infection.

Vezzani et al. (2008) found that elevated cytokine levels increase neural excitability, potentially destabilising inhibitory-excitatory balance in cognitive circuits. In more extreme cases, cytokine storms may result in broad neurochemical dysregulation, linked to executive and emotional dysfunction (Leisman et al., 2020; Hu et al., 2022).

Cognitive Effects of COVID-19

Given the previously outlined neuropathological effects of SARS-CoV-2, it is vital to investigate the cognitive consequences of such disruptions. The related neuropathology has been shown to affect frontal and temporal brain regions associated with executive control, attention, memory, and processing speed (Nasir et al., 2025). Consequently, cognitive impairments have emerged as some of the most frequent and debilitating symptoms in both the acute and post-acute phases of infection.

Long-Covid /PCC

One of the most recognised post-infectious complications is Post-Acute COVID-19 Syndrome (PACS) or Long-Covid, also referred to more recently by the World Health Organization (2025b) as Post-COVID-19 Condition (PCC). PCC is characterised by a constellation of symptoms that emerge typically within three months of infection, persist for at least two months, and are not explained by alternative diagnoses (WHO, 2025b). These symptoms affect multiple systems and include both physiological and neuropsychiatric manifestations. Cognitive dysfunction—commonly referred to as “brain fog”—is among the

most frequently reported and persistent symptoms (refer to Table 1), often encompassing concentration difficulties, memory lapses, disorientation, and slowed cognitive processing (Jennings et al., 2022; Nalbandian et al., 2021).

Since the start of the pandemic, millions of people have developed PCC and, according to estimates, six out of every hundred people who contract COVID-19 experience this syndrome (Al-Aly et al., 2024).

Table 1

Some symptoms of PCC adapted from Nalbandian et al. (2021)

Pulmonary	**Cardiovascular**	**Neuropsychiatric**
Dyspnea	Palpitations	Fatigue
Decreased Exercise Capacity	Chest Pain	Cognitive impairment (brain fog)
Hypoxia	Tachycardia	Anxiety

Emerging evidence suggests that cognitive impairments may be associated with persistent inflammatory responses and may occur independently of the severity of the initial infection. For instance, Pallanti et al. (2023) identified a correlation between elevated inflammatory markers and reduced executive functioning in individuals experiencing post-COVID symptoms.

Within the Maltese context, Xuereb et al. (2023) reported long-term follow-up findings showing that a significant proportion of individuals continued to experience symptoms—particularly fatigue, dyspnoea, and cognitive complaints—up to two years after infection. While certain sensory symptoms showed some recovery, neurocognitive symptoms

remained persistent in a subset of patients. These findings are echoed in local media reporting, with cases of ongoing “brain fog,” post-exertional fatigue, and difficulties with basic cognitive tasks being cited more than a year post-infection (Debono, 2024). Although anecdotal in nature, these accounts highlight the need for systematic investigations into possible sequelae in the local population.

Cognition in Severe COVID-19

Severe cases of COVID-19, particularly those requiring hospitalisation or intensive care, have consistently been associated with persistent cognitive impairments. Patients with pre-existing comorbidities and advanced age are especially vulnerable to complications such as thromboembolism, respiratory failure, and systemic hypoxia—factors that have been linked to neurological dysfunction (Gao et al., 2021; CDC, 2024). According to European data, hospitalisation rates among confirmed cases have ranged between 5% and 15% (ECDC, 2023). In Malta, while detailed national statistics are limited, data from the first wave indicated that approximately 21% of confirmed cases required hospitalisation (Micallef et al., 2020).

Neuropsychological research has shown that individuals recovering from severe COVID-19 often display impairments in executive functioning, attention, and processing speed. Jaywant et al. (2021) evaluated cognitive performance in hospitalised patients with hypoxemic respiratory failure, finding that 47% exhibited impaired set-shifting and 40% displayed slowed processing speed approximately six weeks post-admission. These findings were based on the Brief Memory and Executive Test (BMET; MacPherson et al., 2002), a tool designed to assess higher-order cognitive domains.

Similarly, Ollila et al. (2022) reported persistent executive and attentional deficits in ICU-treated individuals, further reinforcing the view that executive dysfunction constitutes a

central cognitive consequence of SARS-CoV-2 infection. Although the neuropsychological tools used in these studies will be discussed in detail later on, their convergence across findings supports the notion that EF is particularly vulnerable in post-ICU populations.

In rehabilitation contexts, Alemanno et al. (2021) found that over 80% of post-COVID inpatients demonstrated neuropsychological abnormalities. Although assessed using general screening measures such the Mini Mental State Exam (MMSE; Folstein et al., 1975), and the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), these results still underscore the widespread cognitive burden of severe illness. Notably, while such tools are limited in their sensitivity to executive deficits, their findings nonetheless align with more targeted assessments in highlighting impairments in attention, planning, and cognitive flexibility.

Mild COVID-19 and Cognition

While cognitive dysfunction has been widely documented in hospitalised or severe COVID-19 cases, a growing body of research suggests that individuals with mild or moderate illness may also experience persistent cognitive symptoms, particularly in the domain of executive functioning. This area remains underexplored, especially in working-age, non-hospitalised populations—such as the Maltese demographic examined in the present study.

Woo et al. (2020) were among the first to highlight the limited understanding of neurocognitive outcomes in non-hospitalised individuals with COVID-19. Their findings revealed that even in the absence of severe respiratory symptoms, participants exhibited impairments in both short-term memory and executive functioning, including difficulties with delayed recall and attentional control. This early evidence pointed to the possibility that mild COVID-19 may affect cognition through mechanisms independent of hypoxia or structural brain injury.

Matos et al. (2021) similarly reported a *subacute cognitive syndrome* in patients with mild-to-moderate COVID-19, suggesting that disruptions in cortico-subcortical associative circuits may occur independently of hypoxia or systemic inflammation.

Further evidence for executive dysfunction in non-hospitalised populations comes from Henneghan et al. (2022), who found that approximately 40% of their sample exhibited deficits in cognitive flexibility and attentional control. Similarly, Pallanti et al. (2023) linked post-infection inflammatory markers to reduced performance on executive function tasks, including the D-KEFS Trail Making Test. Importantly, this study demonstrated that even in cases of mild illness, biological markers of inflammation may be the basis of subtle but measurable executive impairments.

More evidence also suggests that even individuals with mild infections may exhibit persistent deficits in domains such as memory, attention, and processing speed. For instance, Hampshire et al. (2021), using an unsupervised online cognitive platform, identified significant reductions in verbal memory performance among non-hospitalised individuals with only minor symptoms. These findings imply that SARS-CoV-2 may affect hippocampal or fronto-temporal circuits through mechanisms unrelated to respiratory severity, such as low-grade neuroinflammation (Radhakrishnan & Kandasamy, 2022; Zorzo et al., 2023).

Similar outcomes were reported by De Pádua Serafim et al. (2024), who found that 11.7% of individuals with mild COVID-19 experienced enduring cognitive impairments—particularly in attention and processing speed—up to 18 months post-infection. These findings align with those of Henneghan et al. (2022), who reported attention as one of the most consistently affected domains in mild-to-moderate post-COVID populations. However, methodological differences across these studies—such as the use of online testing platforms and limited control for demographic confounds—limit the generalisability of their findings.

Introducing Executive Functions

To contextualise the highlighted cognitive impairments, the next section outlines the core components of executive functioning. These will be defined and discussed in relation to their neuroanatomical basis and relevance to everyday behaviour.

Foundations of Executive Function

Interest in the brain's role in behaviour was initiated by early neurological cases such as that of Phineas Gage, whose frontal lobe injury led to dramatic changes in personality and impulse control (Ratiu et al., 2004). While historically important, contemporary research has moved beyond isolated cases to develop theoretical models and psychometric tools for understanding EF.

The term "executive function" was originally introduced by Pribram (1973) to describe the regulatory role of the prefrontal cortex in higher-order cognitive processes. Lezak et al. (2012) provide one of the most comprehensive and widely cited neuropsychological definitions, describing EF as a multidimensional construct involving goal formation, planning, initiation, and the monitoring of purposeful behaviour. These processes are essential for successful problem-solving, emotional regulation, and adaptive functioning in dynamic environments.

Although there is no single universally accepted model of EF, various frameworks have been proposed to characterise its structure and component processes. The following section critically examines influential models of EF, with particular attention to their empirical support and relevance to clinical assessment.

Models of EF

One of the earlier theoretical frameworks for executive control is the working memory model developed by Baddeley and Hitch (1974). This model introduced the *Central*

Executive as a supervisory component responsible for coordinating the *Phonological Loop* and *Visuospatial Sketchpad*. The Central Executive was later refined by Baddeley (1986) to incorporate ideas from Norman and Shallice's (1986) *Supervisory Attentional System* (SAS), which distinguished between automatic and controlled processes. However, while foundational, this model has been criticised for lacking specificity in defining the executive processes it describes.

In contrast, Miyake et al. (2000) proposed a more empirically measurable framework based on latent variable analysis, identifying three core components of executive functioning: inhibition, shifting, and updating. These functions were shown to be both distinct and interrelated, supporting the idea that EF is best conceptualised as a unity/diversity structure (Miyake & Friedman, 2012). The model's strength lies in its psychometric clarity, making it widely adopted in both experimental and clinical settings (Friedman et al., 2008; Jurado & Rosselli, 2007; Rodríguez-Nieto et al., 2022).

Diamond (2006, 2013) similarly emphasised the roles of inhibition, working memory, and cognitive flexibility, but placed greater focus on their role in child development and higher-order abilities like planning and reasoning. Unlike Miyake's framework, which was driven by factor-analytic methods, Diamond's model is more developmental and hierarchical in nature, proposing that complex EF builds on foundational skills. However, Diamond's approach has been critiqued for lacking the same degree of empirical decomposition found in Miyake's work, as studied by Best and Miller (2010) and Karr et al. (2018).

While both models offer relevant insights, the Miyake model (2000) provides a more precise framework for isolating core EF processes such as inhibition, shifting, and updating. These domains closely align with the structure of the test battery employed in the current study. However, higher-order functions such as planning, while not central to Miyake's

framework, are acknowledged in developmental models such as Diamond (2013) and are considered in the interpretation of complex task performance.

Key components of EF

Building on the theoretical rationale outlined above, this section examines the specific executive functions assessed in this study, each of which plays a distinct role in adaptive behaviour and higher-order cognition.

Cognitive Flexibility and Task Switching

Cognitive flexibility refers to the capacity to shift between mental sets, strategies, or behavioural responses in the face of changing task demands or environmental stimuli (Braem & Egner, 2018). It enables individuals to disengage from habitual patterns of thinking and adapt to novel rules or perspectives, and is often conceptualised as a core component of executive functioning. According to Ionescu (2012), cognitive flexibility emerges from dynamic interactions between cognitive and sensorimotor systems, highlighting its complexity beyond purely attentional control.

Theoretical perspectives such as the Cognitive Flexibility Theory (Spiro & Jehng, 1990) propose that this ability is central to problem-solving in ill-structured or ambiguous situations, as it allows individuals to reconfigure knowledge structures as contexts evolve. However, some researchers have questioned whether cognitive flexibility operates independently from working memory or inhibitory control, given their frequent co-activation in task-switching paradigms (Dajani & Uddin, 2015). Additionally, Tello-Ramos et al. (2019) suggest that the neural mechanisms supporting cognitive flexibility, such as neurogenesis, may promote adaptive forgetting—highlighting a potential trade-off between flexibility and memory stability.

Empirical evidence indicates that flexibility is not purely volitional but can be modulated by contextual cues and incentives, suggesting its susceptibility to environmental factors (Braem & Egner, 2018). This raises concerns about the ecological validity of standardised flexibility tasks, which often fail to reflect the fluctuating demands of real-world decision-making (Cañas et al., 2006; Egner & Siqi-Liu, 2024)

In neuropsychological assessment, cognitive flexibility is frequently measured using set-shifting or task-switching tasks. The Trail Making Test (TMT) from the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001)- particularly Condition 4 - is a widely used tool for this purpose. While the TMT provides quantifiable data on switching and sequencing ability, it has been criticised for merging cognitive flexibility with processing speed and visual scanning (Higginson et al., 2013). These psychometric limitations are particularly important when assessing subtle executive deficits in non-hospitalised or high-functioning individuals with a history of COVID-19.

Given emerging evidence of post-COVID executive dysfunction, including attentional and mental shifting difficulties (Zhou et al., 2020), cognitive flexibility was selected as a key domain in the present study. Its role in adaptive functioning and its sensitivity to disruption make it particularly relevant when examining the cognitive sequelae of SARS-CoV-2 in non-hospitalised individuals.

Inhibition

Inhibitory control refers to the ability to suppress automatic, dominant, or prepotent responses in favour of goal-directed behaviour (Miyake et al., 2000; Friedman & Miyake, 2004). It is widely recognised as a foundational executive function, enabling individuals to manage interference, regulate impulses, and maintain task-relevant focus. While inhibition is often treated as a unitary construct, researchers have distinguished between types such as response inhibition (withholding an action) and interference control (ignoring irrelevant

stimuli), each with distinct neural correlates and cognitive demands (Bissett et al., 2009; Nee et al., 2007).

One influential framework is the task-specific inhibition hypothesis (Rogers & Monsell, 1995), which posits that switching between tasks involves the temporary suppression of the previous task set. If the new task requires a similar or overlapping response, performance may be impaired due to residual inhibition—highlighting the complexity of cognitive control in dynamic environments (Liu & Zhang, 2020). Additionally, the stop-signal paradigm has been instrumental in quantifying response inhibition, though its ecological validity has been questioned in relation to real-life multitasking or social decision-making (Logan, 1994; Verbruggen & Logan, 2008).

Inhibition is commonly measured using interference-based tasks such as the Go/No-Go task and the Colour-Word Interference Test (CWIT) from the Delis–Kaplan Executive Function System (D-KEFS; Delis et al., 2001a). The CWIT includes conditions that require participants to suppress habitual reading responses in favour of naming ink colours, as well as switching between these rules. These tasks provide robust metrics for inhibitory performance but have been criticised for their limited ecological validity, as they may not capture the multifaceted and context-sensitive nature of real-world inhibitory failures (Snyder et al., 2015).

Unlike cognitive flexibility, which focuses on adaptability, inhibitory control underpins behavioural regulation and the suppression of irrelevant or inappropriate responses—capacities that may be particularly strained in individuals recovering from even mild infections. By targeting this domain, the study aims to capture subtle cognitive control impairments that may not be immediately observable but can impact real-world functioning.

Planning

Planning is widely recognised as a higher-order executive function that enables individuals to formulate, evaluate, and execute sequences of actions in pursuit of a goal (Diamond, 2013; Lezak et al., 2012). It involves anticipating future outcomes, setting objectives, organising steps in logical order, and adjusting strategies based on feedback or changing conditions. While not always included as a "core" EF domain in latent variable models (e.g., Miyake et al., 2000), planning is frequently positioned as an integrative function that draws upon working memory, inhibition, and cognitive flexibility to support complex, goal-directed behaviour (Anderson, 2002).

The cognitive demands of planning require sustained attention, the inhibition of impulsive responses, the maintenance of sequential information, and ongoing performance monitoring (Levine et al., 2000). These interrelated components are particularly evident in ecologically oriented models of executive function, where planning is essential for adaptive functioning in everyday tasks such as financial management, organising work activities, or navigating complex environments (Burgess et al., 2006).

Therefore, in neuropsychological contexts, planning is assessed using tasks that require the mental simulation and coordination of future actions. The Tower of Hanoi and Tower of London tasks are classic examples, where individuals must reorder objects according to specific constraints using the fewest possible moves (Sullivan et al., 2009). The Rey-Osterrieth Complex Figure Test (ROCFT) can also provide qualitative insights into planning, as the organisation and sequencing of figure reproduction reflect the individual's strategic approach (Ogino et al., 2009). Another widely used measure is the Key Search subtest from the Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson et al., 1996), which asks individuals to devise an efficient search strategy for a lost key in a large field—a task designed to approximate real-world planning demands.

However, the ecological validity of these measures varies considerably. Some, like the Tower tasks, may lack generalisability to real-life contexts due to their abstract, rule-bound nature (Chaytor & Schmitter-Edgecombe, 2003). Even tests like the BADS, though more contextually grounded, may be influenced by cultural or experiential familiarity with the task (Norris & Tate, 2000). Hanna-Pladdy (2007) further highlights the dissociation between laboratory-based planning performance and the types of executive decision-making required in occupational or daily life, suggesting that traditional neuropsychological tools may underestimate real-world dysfunction.

Given its complexity and integration of multiple cognitive domains, planning is considered particularly sensitive to prefrontal cortex functioning - especially the dorsolateral and orbitofrontal regions - areas frequently implicated in both traumatic and inflammatory brain conditions (Alvarez & Emory, 2006), such as COVID-19.

Neuropsychological Assessments of Executive Functions

Assessing executive functioning requires the integration of multiple cognitive processes, often through complex and novel problem-solving tasks (Walsh, 1978). However, standardising these tasks across individuals presents challenges, as what is considered "complex" can vary with age, context, and cognitive reserve (Alexander & Stuss, 2000). To address these issues, neuropsychological assessments have increasingly prioritised ecological validity—the extent to which test performance reflects real-world functioning (Chaytor & Schmitter-Edgecombe, 2003; Doebel, 2020).

The Behavioural Assessment of Dysexecutive Syndrome **(**BADS; Wilson et al., 1996) was developed to simulate real-life executive demands and includes six subtests targeting planning, problem-solving, rule shifting, and judgment. It also incorporates the Dysexecutive Questionnaire (DEX), a self- and informant-rated inventory that captures behavioural symptoms associated with executive dysfunction (Wilson et al., 1996). BADS

has demonstrated acceptable internal consistency (Cronbach's α ranging from .63 to .82 across subtests) and good inter-rater reliability (Bennett et al., 2005; Norris & Tate, 2000). Importantly, it is valued for its ecological relevance, particularly in assessing goal-directed behaviour, which is often difficult to capture through traditional laboratory-based tasks. However, BADS has been criticised for its relatively limited sensitivity to subtle deficits, particularly in high-functioning or non-clinical populations, as stated by Spooner & Pachana (2006).

The Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001a) is a widely used battery that targets multiple components of EF, including inhibition, cognitive flexibility, verbal fluency, and planning. It comprises nine modular tests, such as the Trail Making Test, Color-Word Interference, and Tower Test, which can be administered individually or as a full battery for greater evaluation flexibility (Shunk et al. 2006). D-KEFS provides strong psychometric support, with reported test–retest reliabilities ranging from .62 to .80 and well-established normative data stratified by age and education (Delis et al., 2004; Homack et al., 2005). Despite this, the D-KEFS has been criticised for its task impurity—that is, the influence of non-executive processes like processing speed and motor control on test performance (Delis et al., 2001b; Yochim et al., 2007) Moreover, while D-KEFS is considered robust for group-level comparisons, some subtests may lack ecological validity when used in isolation (Baron, 2004).

Both batteries are more complex than widely used screening tools like the MoCA or MMSE, which, although common in post-COVID cognitive studies, lack the specificity and depth required to assess distinct executive domains (Lezak et al., 2012). Given the limitations observed in prior research, this study employs selected subtests from both the BADS and D-KEFS to assess inhibition, cognitive flexibility, and planning.

Other Assessments

In addition to performance-based tasks, the BADS includes the Dysexecutive Questionnaire (DEX), a self- and informant-report tool designed to assess behavioural symptoms of executive dysfunction (Wilson et al., 1996). Bennett et al. (2005) evaluated the DEX's sensitivity in a sample of 64 individuals with traumatic brain injury, with ratings provided by both a neuropsychologist and an occupational therapist. Their findings indicated that few measures strongly predicted DEX scores, suggesting that a combination of BADS subtests and other tools may be necessary to accurately identify executive dysfunction in clinical settings. Similarly, Azouvi et al. (2014) emphasised that the DEX captures both cognitive and emotional dimensions of dysexecutive symptoms, offering a more holistic understanding of their impact on daily functioning.

Beyond the measures discussed, other widely used EF tasks include the Iowa Gambling Task (Bechara et al., 1994), the Wisconsin Card Sorting Test (WSCT; Berg, 1948; Grant & Berg, 1948), and the Go/No-Go task (Gordon & Caramazza, 1982). Executive function is also frequently evaluated through clinical observation and performance patterns on tasks not explicitly designed for EF, reflecting its central role across cognitive domains.

Executive Function and Brain Networks

Early insights into the neural basis of EF emerged from lesion studies. The case of Phineas Gage, who developed marked changes in personality and goal-directed behaviour following a traumatic frontal lobe injury, remains a foundational reference point (Ratiu et al., 2004). Similarly, Broca's identification of language deficits in a patient with a frontal lesion (Broca, 1861) underscored the critical role of the frontal cortex in higher-order cognitive

functions. These observations laid the groundwork for modern neuropsychology and highlighted the prefrontal cortex (PFC) as a hub for executive processing.

Building on these early findings, more modern studies have used advanced neuroimaging techniques, such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), to identify the distributed networks supporting executive control. These studies confirm that EF deficits are associated not only with localized frontal lobe damage but also with disruptions in large-scale brain networks connecting prefrontal, subcortical, and parietal regions (Bonelli & Cummings, 2007; Chung et al., 2014; Stuss, 2011).

The prefrontal cortex

The prefrontal cortex (PFC) plays a central role in EF, supporting functions such as working memory, temporal sequencing, planning, cognitive flexibility, rule learning, and decision-making (Domenech & Koechlin, 2015; Roberts et al., 1998; Yuan & Raz, 2014). It facilitates these capacities through top-down control, exerting influence over other cortical and subcortical systems to manage behaviour and cognition (Jones & Graff-Radford, 2021). Importantly, the PFC operates through reciprocal circuits with the striatum, and is modulated by neurotransmitters including dopamine, serotonin, and noradrenaline—all of which are involved in enabling adaptive and flexible behaviour (Kehagia et al., 2010).

The dorsolateral prefrontal cortex (dlPFC) has been consistently linked to working memory, planning, and cognitive flexibility (Turnbull et al., 2019; Farzaneh et al., 2021). Deficits in this region are associated with impaired hypothesis generation and disorganised goal-directed behaviour (Royall et al., 2002). Interestingly, the dlPFC has also been implicated in pain modulation, which may overlap with its role in attentional and cognitive regulation (Seminowicz & Moayedi, 2017).

The ventromedial prefrontal cortex (vmPFC) and orbitofrontal cortex (OFC) are associated with emotional regulation, inhibition, and social decision-making (Ardila, 2008; Lezak et al., 2012; Stuss, 2011). These areas contribute to evaluating reward and risk, particularly in ambiguous or emotionally salient contexts (Bechara et al., 2000). Functional impairments in the vmPFC/OFC regions have been linked to poor self-monitoring, impulsivity, and difficulties with emotional reasoning—each of which may manifest post-COVID.

Frontal-Subcortical Circuits

Beyond the PFC, EF is supported by parallel fronto-subcortical circuits, particularly involving the basal ganglia and thalamus. These circuits are crucial for the integration of emotional, cognitive, and motor functions, and play a key role in the execution of goal-directed behaviour (Haber & Calzavara, 2009). The basal ganglia, for example, support response inhibition and set-shifting, particularly through their interactions with the PFC (Haber, 2003). These functions are directly relevant to the EF components investigated in this study, such as inhibition and cognitive flexibility.

Another critical region is the anterior cingulate cortex (ACC), which monitors for cognitive conflict, detects errors, and regulates attentional allocation under competing demands (Brown, 2005; Swick & Turken, 2002). The ACC is often activated during tasks requiring inhibitory control and complex response selection, linking it to executive domains likely to be affected by neuroinflammatory processes in post-COVID populations.

Other networks. Although prefrontal and subcortical structures form the core EF circuitry, other regions have also been implicated in executive processes. The anterior temporal lobes, for instance, have been associated with inhibition and social cognition, including empathy and behavioural regulation (Eslinger et al., 2011; Hornberger et al., 2011). Moreover, regions of the parietal cortex—notably the superior parietal lobule and intraparietal sulcus—contribute to spatial attention, working memory, and multitasking (Collette et al., 2005; Koenigs et al., 2009). These areas are often engaged during executive tasks that involve rule-switching or information updating.

Studies in Post-COVID Populations

Executive functions, supported by prefrontal and fronto-subcortical networks, are particularly vulnerable to biological mechanisms triggered by SARS-CoV-2, including neuroinflammation, hypoxia, and neurotransmitter disruption (Aghagoli et al., 2020; Boldrini et al., 2021). As outlined in the previous sections, these brain-based disruptions overlap with regions responsible for inhibitory control, cognitive flexibility, and planning—making executive function a critical domain for post-infection cognitive assessment, the focus for this study. Therefore, building on the neuroanatomy of EF , the next section reviews empirical findings on the deficits present in this domain that have been observed in individuals after having mild COVID-19.

A key distinction lies in how studies balance breadth versus depth of cognitive assessment. For instance, Delgado-Alonso et al. (2022) used an extensive battery that included both standardised paper-based tests (e.g. Stroop (Stroop, 1935), Digit Span (Wechsler, 2008), BADS (Wechsler, 2008)) and computerised assessments (e.g. Trail Making Test). This allowed for a nuanced exploration of inhibition, planning, and attention in mildly affected patients. By contrast, Zhou et al. (2020) employed a much narrower digital battery consisting of the Continuous Performance Test (CPT; Conners et al., 2003), Digit Span

(Wechsler, 2008), and Trail Making Test, and while they reported significant deficits in sustained attention and inhibitory control, the tasks used lacked ecological depth. Interestingly, Zhou's study uniquely linked C-reactive protein levels with cognitive performance, suggesting a biological basis for executive impairments, although this was not explored further in Delgado-Alonso's design.

Sample size and population characteristics also vary meaningfully across studies, influencing generalisability. Becker et al. (2023) stands out for its large sample of 417 post-COVID patients, compared to 151 matched controls. They reported significantly higher odds of executive dysfunction—particularly in cognitive flexibility—even among those treated solely in outpatient settings (Becker et al., 2023). This contrasts with Arelis et al. (2025), whose sample of 60 Mexican patients with mild COVID-19 showed impairment only on the Mexican-normed Modified Wisconsin Card Sorting Test (M-WCST; Nelson, 1976), with no significant findings on the Stroop (Stroop, 1935) or TMT (Delis et al., 2001a). This discrepancy could reflect either cross-cultural or methodological differences; notably, Arelis et al.'s (2025) use of culturally normed tools adds precision, while Becker's battery—though large-scale—relied heavily on brief screeners like TMT and Number Span.

Control groups also vary and affect interpretability. Zhou et al. (2020), Becker et al. (2023), and Arelis et al. (2025) all included control groups matched by age and education, strengthening their conclusions. On the contrary, García-Sánchez et al. (2022) and Delgado-Alonso et al. (2022) relied on normative data or comparisons within symptomatic groups.

García-Sánchez et al.'s (2022) study involved 63 participants with subjective complaints and used principal component analysis to identify overlaps between attention and executive function. Despite the absence of a control group, their approach provided insight into the co-occurrence of deficits, and notably, they found impairments were largely unrelated to

severity, biomarkers, or affective symptoms—suggesting a broader vulnerability of EF to COVID-19's aftermath (García-Sánchez et al., 2022). Meanwhile, Delgado-Alonso et al. (2022) found similar EF impairments, but also reported associations with anxiety and sleep dysfunction—variables that other studies either did not measure or found unrelated Delgado-Alonso et al. (2022).

Overall, across all studies, a key methodological concern lies in the types of tools used to measure EF. While studies like Delgado-Alonso et al. (2022) and Arelis et al. (2025), incorporated performance-based assessments for mild cases (e.g. Tower of London, M-WCST), the others relied on simpler screeners such as the CPT, or TMT. Moreover, to the researcher's knowledge, no study focused on a single executive function. This limits the ecological validity of many findings—particularly given the complex, goal-directed nature of executive functions.

Rationale for study

Systematic reviews like Panagea et al. (2024) help contextualise these individual studies, confirming that executive dysfunction, attention, and memory are the most commonly affected domains across the literature. However, they also highlight a lack of consistency in test selection, underrepresentation of non-hospitalised patients, and limited cross-cultural research (Panagea et al., 2024) —all areas this study attempts to address.

As discussed in previous sections, EF are essential cognitive processes that enable individuals to plan, focus attention, remember instructions, and manage multiple tasks - skills crucial for effective job performance. Research indicates that individuals recovering from COVID-19, including those with mild cases, may experience persistent executive dysfunction. These cognitive impairments can affect daily activities and occupational responsibilities, leading to challenges in maintaining job performance and productivity (Buer

et al., 2024; Thompson et al., 2023). Given the integral role of executive functions in job performance and the observed cognitive impacts of COVID-19, focusing on the working-age population is both timely and necessary.

Remarkably, the BADS, as used in Delgado-Alonso et al.'s (2022) study, remains underutilised in post-COVID-19 research despite its closer approximation to real-world executive demands. This reflects a broader methodological gap in the field, where ecologically valid, performance-based assessments are often overlooked in favour of more general or screening-oriented tools. The inclusion of both BADS and D-KEFS in the present study responds directly to this gap.

Hence, while much of the existing literature has concentrated on older, hospitalised, or clinically referred samples, relatively little attention has been given to working-age, community-dwelling adults recovering from mild to moderate COVID-19. The current study addresses this oversight by targeting a Maltese adult population while utilising strong neuropsychological measures, thereby contributing both demographically and methodologically to a diverse yet important area of research.

Conclusion

In summary, the reviewed literature highlights the neurological basis, theoretical foundations, and observed executive function impairments associated with COVID-19. While progress has been made, notable gaps remain, particularly concerning non-hospitalised, working-age populations and the use of ecologically valid assessment tools. The following chapter outlines the methodology employed to address these issues within the context of the present study.

Chapter 3: Methodology

Introduction

This chapter details the methods used to examine how performance on executive functioning (EF) tests differs between individuals with a history of acute COVID-19 and those without. The theoretical framework, research design and the study sample are initially outlined, followed by a review of the assessment tools used for data collection. Ethical concerns and approval processes are also addressed. Finally, the chapter highlights the research hypotheses and the methods of statistical analysis used to examine the data.

The Theoretical Framework

This study uses a post-positivist paradigm, which acknowledges that while objective observation and measurement are essential, knowledge is inevitably shaped by bias, context, and interpretation (Phillips & Burbules, 2000; Maksimović & Evtimov, 2023). Although rooted in positivist traditions—such as hypothesis testing and statistical analysis (Mahardini et al., 2024; Slevitch, 2011)—post-positivism recognises the limitations of absolute objectivity, especially in the study of complex psychological constructs like EF. This approach allows for a critical yet empirical investigation of cognitive outcomes following COVID-19, aligning with the study's aim to explore measurable differences while remaining aware of contextual influences.

Research Design

A quantitative design was adopted to examine the relationship between COVID-19 infection and performance in EF tests in working-age adults in Malta. A quantitative approach was selected for its capacity to produce objective, numerical data, enabling the testing of hypotheses through statistical analysis and the identification of potential associations between variables (Noyes et al., 2019; Alford & Teater, 2025). This design is particularly suited to

exploring measurable cognitive differences based on COVID-19 status, aligning with the study's aim to evaluate EF outcomes using standardised tools.

Informed by positivist principles, this methodology is grounded in the belief that psychological phenomena can be observed, measured, and analysed independently of the researcher (Park et al., 2020). The approach prioritises internal and external validity through structured data collection and predefined variables (Farhady, 2022), supporting the study's efforts to investigate theoretical assumptions in a controlled manner.

The independent variable in this study was COVID-19 history (presence or absence of past infection), while the dependent variables were scores from performance-based EF assessments. These variables were analysed using validated subtests designed to capture distinct cognitive domains such as inhibition, planning, and cognitive flexibility. Further details regarding instruments, sampling procedures, and statistical methods are provided in the following sections.

Participants

Participants were recruited using convenience sampling, a non-probability method based on accessibility and willingness to participate (Andrade, 2020). This approach was selected due to its practicality and suitability for the study's local context, allowing the efficient recruitment of working-age adults from the Maltese population (Etikan et al., 2016; Acharya et al., 2013).

Inclusion criteria were established to align with the study's objectives:

- Participants were required to be Maltese nationals, as the research focused on executive functioning within this specific cultural and linguistic context.
- Participants were aged between 18 and 64 years, targeting a working-age adult population.

- Proficiency in English was necessary, as all EF assessments were administered in English and standardised accordingly.

A total of 70 individuals participated in the study. The sample comprised 48 females (68.6%) and 22 males (31.4%), with ages ranging from 18 to 61 years.

Data Collection Tools

This study utilised two primary data collection tools: a researcher-developed demographic questionnaire and a set of standardised neuropsychological assessments targeting EF.

Demographic Questionnaire

Participant data were gathered using a 21-item questionnaire developed by the researcher (Appendix C). Items were adaptive based on participants' COVID-19 history; for instance, individuals who tested negative were not required to answer follow-up questions related to infection experiences.

The questionnaire captured demographic variables including age, gender, education level, employment status, and occupation. To assess COVID-19 exposure, participants reported infection status, number of infections, and illness severity. Severity was determined through indicators such as hospitalisation, ICU admission, oxygen therapy, and medication use.

To explore perceived cognitive impacts, the questionnaire included open-ended questions addressing:

- Cognitive difficulties during and after recovery
- Current cognitive challenges
- Lifestyle adjustments due to cognitive symptoms

Participants also completed a checklist for pre-existing medical or psychological conditions and indicated their availability for in-person neuropsychological testing.

Neuropsychological Assessments

The subtests were chosen from two standardised batteries – the Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson et al., 1996) and the Delis-Kaplan Executive Function System (DKEFS; Delis et al., 2001a). Two subtests from the former were chosen; Zoo Map Test and Rule Shift Cards Test. Two further tests from the D-KEFS were also used; Colour Word Interference Test, and the Trail Making Test.

These subtests were chosen for their validity in testing core EF domains (planning, cognitive flexibility, inhibition, and attention) while remaining brief, practical, and culturally generic. Although the batteries were not standardised for the Maltese population, chosen subtests were reviewed for cultural neutrality and minimal reliance on local knowledge in order to reduce contextual bias. Tools with shorter administration times were prioritised to maximise participant engagement and ensure data reliability across a diverse adult population.

Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001a)

The Delis-Kaplan Executive Function System (D-KEFS *Delis et al., 2001a*) is a widely used, performance-based battery designed to assess various components of executive functioning. It consists of nine independent subtests, allowing for targeted evaluation of specific EF domains associated with frontal lobe processes. For this study, two subtests were selected: the Colour-Word Interference Test (CWIT) and the Trail Making Test (TMT). These tools were chosen for their sensitivity to key EF domains—namely, response inhibition and cognitive flexibility—which are directly aligned with the study's focus on cognitive changes following COVID-19. Scoring was conducted according to the D-KEFS manual, with raw

scores based on task completion time converted into age-scaled scores. Scores ranging from 8 to 12 were considered average; scores below 8 indicated potential impairment, and scores above 12 reflected above-average performance.

Colour-Word Interference Test (Delis et al., 2001a). The Colour-Word Interference Test (CWIT) is based on the original Stroop paradigm (Stroop, 1935) and consists of four conditions that assess inhibition and cognitive switching (Delis et al., 2001; Scarpina & Tagini, 2017). The first condition, Colour Naming, requires participants to name coloured patches. The second, Word Reading, involves reading colour words printed in black ink. The third condition, Inhibition, measures the ability to suppress automatic responses by having participants name the ink colour of incongruent colour words. In the fourth and most complex condition, Inhibition/Switching, participants must alternate between naming the ink colour and reading the word depending on whether the stimulus is enclosed in a box.

Each condition was timed and scored based on both accuracy and speed, with scaled scores calculated using age-referenced conversion tables. Although factors such as fatigue and reduced processing speed can impact performance, evidence suggests that impairments in inhibition and switching are the primary sources of difficulty in clinical and post-viral populations (Dimoska-Di Marco et al., 2011).

Trail Making Test (Delis et al., 2001a). The Trail Making Test (TMT) includes five conditions that assess cognitive flexibility and visual attention (Delis et al., 2001a). Two conditions were administered in this study: Number Sequencing (Condition 2) and Number-Letter Switching (Condition 4). In Number Sequencing, participants are required to connect numbers in sequential order, while Number-Letter Switching involves alternating between numbers and letters in ascending sequence (e.g., 1-A-2-B). The latter condition provides a more comprehensive assessment of cognitive flexibility and divided attention. Similar to the

CWIT, task completion times and errors were recorded and converted into age-scaled scores following the manual's guidelines.

Psychometric Properties. The D-KEFS subtests used in this study have demonstrated acceptable psychometric properties. Internal consistency ranges from .57 to .81 for the TMT and .62 to .86 for the CWIT (Shunk et al., 2006), and the CWIT has shown moderate test-retest reliability (.62–.76) across conditions (Delis et al., 2001b). These findings support the reliability of the subtests in measuring key aspects of executive functioning. In terms of construct validity, the CWIT's Inhibition/Switching condition enhances the clinical sensitivity of the standard Stroop paradigm (Anderson et al., 2017), and the TMT has been validated as a robust measure of executive control (Sánchez-Cubillo et al., 2009).

However, certain limitations must be acknowledged. Both subtests are influenced by demographic factors such as age and education level. Research suggests that younger, highly educated individuals may reach ceiling performance levels, particularly on simpler conditions such as TMT Number Sequencing (Tombaugh, 2004; Fernandez & Marcopulos, 2008). While the CWIT has demonstrated sensitivity to age-related declines in inhibition and flexibility (Adólfsdóttir et al., 2016), its ability to detect subtle or acute impairments in younger, high-functioning populations may be limited. Despite these considerations, the selected D-KEFS subtests remain appropriate for this study given their clinical relevance, efficiency, and alignment with the targeted executive domains.

Behavioural Assessment of Dysexecutive Syndrome (BADS; Wilson et al., 1996)

The Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson et al., 1996) is a performance-based battery designed to assess executive dysfunction in real-life contexts. It focuses on core executive processes including planning, cognitive flexibility, and problem-solving, making it particularly suitable for evaluating everyday EF impairments.

Two subtests from the BADS were used in this study: the Rule Shift Cards Test and the Zoo Map Test, selected for their relevance to the domains under investigation and their applicability to functional, real-world scenarios

Rule Shift Cards Test (Wilson et al., 1996). The Rule Shift Cards Test evaluates cognitive flexibility and the ability to shift between rule sets. The task involves two conditions using a set of red and black playing cards. In the first trial, participants respond "yes" to red cards and "no" to black cards. In the second trial, they must respond based on whether the current card matches the colour of the previous one. To minimise the influence of memory limitations, rules were printed and kept visible throughout the task. Although the first trial serves primarily as practice, performance is assessed based on accuracy and completion time during the second trial. Scoring involves assigning a profile score, as shown below in Table 2, based on the number of errors and time taken; if trial two exceeds 67 seconds, one point is deducted. A profile score below 4 may indicate impaired rule-shifting or inhibitory control.

Table 2

Scoring of the Rule Shift Cards Test

Total Errors	**Profile Score**
0	4
1-3	3
4-6	2
7-9	1
≥ 10	0

Zoo Map Test (Wilson et al., 1996). The Zoo Map Test assesses planning ability through a simulated real-world navigation task. In Part 1, participants independently devise a route to visit a list of zoo locations while adhering to specific rules. In Part 2, they follow a pre-determined path, still observing the same constraints. The task evaluates strategic planning, rule-following, and flexibility in execution. Scoring is based on both route accuracy and adherence to task rules. Errors such as missed locations or route violations reduce the score, while correct sequencing increases it. Profile scores are derived from raw scores (Table 3), with penalties applied for prolonged planning or task execution times (over 15 and 123 seconds respectively).

Table 3

Scoring of the Zoo Map Test

Raw score	**Profile Score**
16	4
11-15	3
6-10	2
1-5	1
≤ 0	0

Psychometric Properties. The psychometric properties of the BADS are well-established. The battery demonstrates high inter-rater reliability (≥0.88) and strong construct validity, particularly in distinguishing individuals with neurological impairments from healthy controls (Wilson et al., 1996; Norris & Tate, 2000). Standardisation was based on a normative sample of 216 adults aged 16 to 87, stratified by IQ using the National Adult

Reading Test (NART). While test-retest reliability varies across subtests—with the Key Search and Temporal Judgement tasks demonstrating the highest stability—this variability is considered acceptable given the novelty-dependent nature of EF assessments (Lezak et al., 2012; Strauss et al., 2006).

Cultural and demographic factors should also be considered when interpreting results. Studies have shown significant performance differences across ethnic groups, particularly on the Zoo Map Test (Proctor & Zhang, 2008). Nonetheless, the BADS has demonstrated moderate diagnostic sensitivity, correctly classifying 84% of healthy adults and 64% of individuals with traumatic brain injury (Norris & Tate, 2000), further supporting its clinical relevance in detecting dysexecutive symptoms.

General Procedures and Ethical Compliance

Ethical approval for this study was formally acknowledged by the Faculty Research Ethics Committee (FREC) on 31 July 2024 (Appendix A). As the study involved non-vulnerable adults from the general population, no additional ethical clearance was required beyond institutional approval. The application was submitted and retained for record-keeping purposes in accordance with standard university procedures.

Recruitment was initiated through the distribution of an online poster outlining the study's aims and inclusion criteria (Appendix B). Individuals who expressed interest were asked to provide an email address, after which they were sent a detailed Participant Information Sheet (Appendix D). This document outlined the study's purpose, procedures, potential risks, and ethical safeguards. Participants were encouraged to share the study details with eligible peers, and all were informed that participation was entirely voluntary. To ensure anonymity and confidentiality, each participant was assigned a unique identifier (e.g., P0XX), which was used to label all data collected. This identifier was used consistently across all

datasets to dissociate personal information from responses. Signed informed consent was obtained prior to participation (Appendix E), and all participants had the opportunity to ask questions before agreeing to take part.

Data collection sessions were scheduled at times convenient for the participants and conducted in private, quiet environments to minimise distractions. Each session lasted approximately 20 to 30 minutes, depending on the participant's pace. Participants were explicitly informed of their right to withdraw from the study at any time, without providing a reason and without penalty. They were also advised that data could be withdrawn provided it remained identifiable.

All personal information and signed consent forms were stored separately from the research data to preserve confidentiality. Where participants requested feedback, a brief summary of performance results was provided, accompanied by a disclaimer noting that the results were for research purposes only and did not constitute diagnostic information.

Research Hypotheses and Method of Data Analysis

The primary aim of this study was to investigate whether a history of acute COVID-19 infection is associated with differences in performance on EF tests among working-age adults in Malta. Participants were categorised into two groups based on self-reported COVID-19 status: those who had previously tested positive (COVID-19 group) and those who had never tested positive (NON-COVID-19 group). Performance data from standardised neuropsychological assessments were analysed using IBM SPSS Statistics (Version 29.0).

The following research questions motivated the study:

- How does COVID-19 affect executive functioning in working-age adults in Malta?

- What is the difference in performance on executive functioning tests between individuals who experienced acute COVID-19 with those who never tested positive for the infection?

Expanding from the research questions, the following is the secondary hypothesis:

- H_1: Individuals who experienced COVID-19 will show significantly lower performance on EF subtests compared to individuals who tested negative for COVID-19.

All data was reviewed for outliers and assumption violations prior to analysis. Normality was assessed prior to analysis and is reported in Chapter 4. Based on the distribution characteristics and sample sizes, both parametric and non-parametric statistical tests were employed (see Table 4 overleaf). Independent-samples t-tests were used where assumptions of normality and homogeneity of variance were met. Where these assumptions were violated, the non-parametric Mann–Whitney U test was used. Group differences in categorical demographic variables (e.g., gender, education) were examined using chi-square tests. All hypotheses were tested at a significance level of $p < .05$.

Table 4

Outline of the statistical tests used to address each hypothesis, including assumption testing procedures

Statistical Test	Purpose
Shapiro-Wilk Test	To assess whether EF performance variables met the assumption of normality in both groups.
Chi-square test	To examine group differences in demographic characteristics (e.g., gender, education level) between COVID-19 and NON-COVID-19 groups.
Independent-samples t-test	To compare CWIT_1 scores between COVID-19 and NON-COVID-19 groups, since this variable met normality assumptions across both groups.[1]
Mann-Whitney U Test	To compare EF performance between COVID-19 and NON-COVID-19 groups when data violated normality assumptions.[1]

Note. Null hypotheses are rejected at a level of significance of 0.05 (p <.05). [1] To investigate $H_{1.}$ 'Performance' relates to the results on the following tasks: Rule Shift Cards Test, Zoo Map Test, Colour Word Interference Test Conditions 1, 2, 3 and 4 and Trail Making Test Conditions 2 and 4. EF = Executive Functioning.

Conclusion

This chapter outlined the theoretical framework, research design, and methodological approach utilised in this study. It included a description of the sample, a summary of the research questions and hypotheses, and an explanation of the data analysis procedures. The

next chapter will present the results of the statistical analyses, beginning with tests of normality and followed by the main findings related to the study's main aim.

Chapter 4: Results

Introduction

This chapter presents the results of the statistical analyses conducted to examine performance differences on executive functioning (EF) tests between individuals with and without a previous diagnosis of COVID-19. Preliminary data screening, assumption testing, and group comparisons are reported, followed by a brief summary of exploratory within-group analyses for the COVID-19 sample.

Initial investigations

Checking for data errors, missing values, and outliers.

Prior to analysis, the dataset was examined for missing data, outliers, and violations of statistical assumptions. All variables fell within valid ranges, with no missing values detected, allowing for the inclusion of the full sample (N = 70).

Outliers can influence statistical analyses, potentially leading to misleading results (Sullivan et al., 2021; Chambers et al., 2004). To address this, outlier detection was conducted for both the COVID-19 and NON-COVID-19 groups using z-scores and box plots. Following Tabachnick and Fidell's (2013) criterion, a z-score threshold of ±3.29 ($p < .001$) was applied, with significant outliers identified accordingly (Mowbray et al., 2019). While box plots indicated several potential outliers, only those exceeding the z-score threshold were retained for further consideration.

A single extreme outlier was identified in Condition 3 of the Colour-Word Interference Test (CWIT_3) within the non-COVID-19 group, based on both z-score criteria ($z = –3.97$) and the Tukey's Fence method. To minimise its potential influence while preserving the full sample, the value was Winsorised to the nearest non-outlier score (5) (see

Table 5). Full methodological details on outlier detection and Winsorisation procedures are provided in Appendix F.

Table 5

Identification of Outlier before and after Winsorization

			OUTLIER		
VARIABLE	Group	Raw Score*	Z-score	Winsorised Raw Score	Winsorized Z-score
CWIT CONDITION 3	NON-COVID-19	1	–3.97	5	-2.62

**Note:* 'Raw score' refers to the scaled score of the outlier on the performance-based test of EF, CWIT_3. CWIT-Colour-Word Interference Test.

Assumption Testing: Normality and Homogeneity of Variance

To establish whether the assumptions required to perform parametric statistical analyses were met, the dataset was checked for normality and homogeneity of variance.

Normality of Data Distribution. Assessing the normality of data distribution is a critical step in statistical analysis (Yap & Sim, 2011). When the assumption of normality is violated, non-parametric tests are often preferred, as they do not depend on the distributional assumptions required by parametric methods (Field, 2018). However, non-parametric tests are generally considered less powerful in detecting significant differences between groups (Hopkins et al., 2018).

The assumption of normality was assessed using both graphical methods and the Shapiro-Wilk test, which is appropriate for small sample sizes (Mishra et al., 2019). Results indicated that most variables significantly deviated from normal distribution ($p < .05$), with the exception of CWIT_1, which met the normality assumption in both groups (see Table 6). Given these violations, non-parametric tests were used for all comparisons except CWIT_1, which was analysed using a parametric approach, known for its greater statistical power.

Table 6

Shapiro Wilk Test of Normality for COVID-19 and NON-COVID-19 groups

		Shapiro Wilk		
Group	**Variable**	**Statistic**	**Df**	**p-value**
COVID-19	Age	.855	27	.001
	Completion	.681	27	.000
	RCS	.614	27	.000
	ZM	.830	27	.000
	CWIT_1	.954	27	.264
	CWIT_2	.946	27	.172
	CWIT_3	.892	27	.009
	CWIT_4	.853	27	.001
	TMT_2	.943	27	.142
	TMT_4	.897	27	.011
NON-COVID-19	Age	.895	43	.001
	Completion	.801	43	.000
	RCS	.768	43	.000
	ZM	.832	43	.000
	CWIT_1	.959	43	.131
	CWIT_2	.906	43	.002
	CWIT_3	.912	43	.003
	CWIT_4	.878	43	.000
	TMT_2	.938	43	.022
	TMT_4	.890	43	.001

Note: RSC=Rule Shift Cards, ZM= Zoo Map, CWIT=Colour Word Interference Test, TMT=Trail Making Test.

As the assumption of normality was violated for the majority of variables, non-parametric tests were selected to ensure robust statistical inference. CWIT_1 was the only measure to meet this assumption in both groups; therefore, a parametric independent samples t-test was applied solely to this variable. While parametric tests are generally considered

robust to minor deviations (Pallant, 2016), non-parametric alternatives are preferred when significant violations are observed (Zimmerman, 1998).

Homogeneity of Variance. Homogeneity of variance was not formally tested, as it is not required for non-parametric tests. The selection of statistical tests was therefore guided by the distribution characteristics of each variable.

General Sample Demographics

The study sample consisted of 70 participants ranging from 18 to 61 years of age (M = 33.49, SD = 12.094). Out of the total 70 participants, 38.6% (n=27) were within the 18-25 age band, 35.7% (n=25) were within the 26-43 age band, and 18% (n=18) were within the 44-61 age band. With regards to gender, 68.6% (n=48) were females and 31.4% (n=22) were males. Participants reported an average of 11.96 years (SD = 13.80) since completing formal education. The majority (30%, n = 21) held a Bachelor's degree. Regarding employment, 74.3% (n = 52) were employed full-time, 10.0% (n = 7) part-time, and the remainder were self-employed (5.7%, n = 4), students (7.1%, n = 5), or unemployed (2.9%, n = 2).

The majority (90%, n=63) did not report a history of neurodevelopmental disorders, previous head injuries or psychiatric conditions. However, 5 participants (7.1%) reported a psychiatric condition, another had a history of past head injuries (1.4%), and one (1.4%) reported both a neurodevelopmental and psychiatric condition.

Participants were categorised based on COVID-19 status: 38.6% (n = 27) were in the COVID-19 group, and 61.4% (n = 43) in the non-COVID-19 group. Among the COVID-positive participants, 66.7% (n = 18) tested positive once, 25.9% (n = 7) twice, and 7.4% (n = 2) three times. None of the COVID-positive participants were hospitalised.

Chi-square tests (Table 7) assessed associations between COVID-19 status and categorical demographic variables (gender, employment status, and pre-existing conditions).

Additionally, Mann–Whitney U tests compared the groups on age and years since education completion. No statistically significant group differences were found for age (U = 460, p = .144) or completion time (U = 480.5, p = .225), indicating demographic comparability.

Table 7

Demographic characteristics of COVID-19 and NON-COVID-19 groups

Variable	**Descriptor**	**COVID-19 (*n*=27)**		**NON-COVID-19 (*n*=43)**		**Comparison**		
		n	%	*n*	%	$\chi 2$	*df*	*p*
Gender	Male	10	37.0	12	27.9	.643	1	.423
	Female	17	63.0	31	72.1			
Employment	Full-Time	22	81.5	30	69.8	6.273	4	.180
	Part-Time	1	3.7	6	14.0			
	Self-employed	3	11.1	1	2.3			
	Student	1	3.7	4	9.3			
	Unemployed	0	0	2	4.7			
Pre-existing conditions	Yes	3	11.1	4	9.3	0.060	1	1.000
	No	24	88.9	39	90.7			

Comparisons between the COVID-19 and NON-COVID-19 groups

Group comparisons were conducted to examine potential differences in executive functioning between individuals with and without a history of COVID-19. Based on

normality assessments, both parametric and non-parametric tests were used where appropriate.

Measures of EF

An independent samples t-test was used to assess performance on Condition 1 of the Colour Word Interference Test (CWIT), the only measure that met the assumption of normality. Results indicated no significant group difference, $t(68) = 0.205$, $p = .423$, with a negligible effect size (*Cohen's d* = 0.05). Mean scores were similar: M = 9.67 (*SD* = 2.22) for the COVID-19 group and M = 9.77 (*SD* = 1.86) for the non-COVID-19 group.

Mann–Whitney U tests were conducted to compare executive functioning (EF) performance between the COVID-19 and non-COVID-19 groups on variables that violated assumptions of normality. As presented in Table X, a statistically significant difference emerged for the Rule Shift Cards (RSC) task, wherein the COVID-19 group (Median = 4) outperformed the non-COVID-19 group (Median = 3), $U = 411.0$, $p = .021$, with a small-to-moderate effect size ($r = .28$). This finding suggests a potential group-level advantage in cognitive flexibility or task-switching ability among individuals with prior COVID-19 infection.

For all other measures—including the Zoo Map (ZM), Colour Word Interference Test (CWIT) Conditions 2 through 4, and Trail Making Test (TMT) Conditions 2 and 4—no statistically significant differences were observed. All p-values exceeded .05, with corresponding effect sizes ranging from negligible to small. These results indicate that, apart from the RSC task, EF performance was broadly comparable between the two groups on measures assessed using non-parametric methods.

In summary, the findings indicate that individuals with and without a history of COVID-19 demonstrated similar performance across most EF tasks. However, the

statistically significant result observed on the RSC task ($p = .021$) may reflect subtle group differences in executive processes such as response selection or inhibition. Beyond this exception, no meaningful group-level disparities in EF performance were detected based on COVID-19 status.

Table 8

Results of group comparisons between the COVID-19 and NON-COVID-19 participants on EF measures – using Mann Whitney U

Variable	**Descriptor**	**COVID-19 (*n*=27)**	**NON-COVID-19 (*n*=43)**	**Comparison**		
		Median	Median	U	*p*	*r*
RCS	Profile Score	4	3	411.0	**.021**	.28
ZM	Profile Score	3	2	442.5	.071	0.22
CWIT	Condition 2	12	12	554.0	.739	0.09
	Condition 3	11	12	562.0	.820	0.03
	Condition 4	12	11	570.0	.898	0.02
TMT	Condition 2	10	8	459.5	.141	0.18
	Condition 4	10	10	556.0	.766	0.04

Note: The bold score indicates a significant value. r = effect size calculated using r= $\frac{Z}{\sqrt{N}}$; RSC= Rule Shift Cards, ZM=Zoo Map, CWIT=Colour Word Interference Test, TMT=Trail Making Test.

Comparisons within the COVID-19 group

Exploratory analyses were conducted within the COVID-19 group to assess potential differences in executive functioning based on gender, age, number of infections, time since education completion, and the presence of pre-existing conditions. However, all subgroup comparisons were substantially underpowered due to small sample sizes, limiting the reliability of statistical inference. No statistically significant differences were observed across any EF measures, and effect sizes were uniformly small. These findings should be interpreted with caution, and detailed results are presented in Appendix G for transparency.

Conclusion

The analysis identified one statistically significant difference between groups, with the COVID-19 group performing better on the Rule Shift Cards (RSC) task, potentially reflecting enhanced cognitive flexibility or inhibitory control. However, this finding was not supported by differences on other EF measures, which may suggest the result was isolated or due to chance variation.

All other comparisons—both between groups and within subgroups of the COVID-19 sample—yielded no statistically significant effects. It is important to note that many of these analyses were limited by small subgroup sizes, reducing statistical power and the confidence with which such findings can be interpreted.

Taken together, the results do not support the hypothesis of widespread EF impairment following COVID-19 in this non-hospitalised sample. A critical discussion of these findings, their implications, and their alignment with existing literature follows in the next chapter.

Chapter 5: Discussion

Introduction

The purpose of this study was to investigate the influence of COVID-19 on EF among working-age adults in Malta, by comparing performance on EF tests between those who tested positive for COVID-19 and those who never contracted the virus.

This discussion critically evaluates the study's findings in relation to existing research on executive functioning following COVID-19 infection. It considers potential explanations for the lack of statistically significant group differences, with attention to test sensitivity, mechanisms of post-infection cognitive difficulties, and demographic influences. The chapter also addresses broader methodological challenges in studying cognitive outcomes in non-hospitalised COVID-19 populations, highlighting the interpretive limitations of the current findings.

Summary of Results

No significant differences in EF performance were found between the COVID-19 and NON-COVID-19 groups across the majority of EF tasks. This indicates that both groups performed similarly on the neuropsychological measures used in this study. The only statistically significant difference observed in the study emerged on the Rule Shift Cards (RSC) subtest of the BADS, where individuals in the COVID-19 group outperformed the NON-COVID-19 group ($p = .021$). Interpretations of this finding are addressed in the cognitive flexibility section below.

Group Differences on Executive Functioning Tests

Overview

It was hypothesised that those who had previously tested positive for COVID-19 would perform differently on the EF tests than those who hadn't. Participants in the COVID-19 group were expected to score worse on executive functioning tests than those in the NON-COVID-19 group.

Inhibition

In the present study, no statistically significant differences were found between the COVID-19 and NON-COVID-19 groups on measures of inhibitory control, including the Colour-Word Interference Test (Conditions 3 and 4) and Trail Making Test (Condition 4). At first glance, this appears to contrast with findings from earlier studies that reported post-COVID inhibitory deficits (such as Zhou et al., 2020; Delgado-Alonso et al., 2022). However, this discrepancy may be more apparent than real when methodological differences are considered.

First, both Zhou et al. (2020) and Delgado-Alonso et al. (2022) included participants with a broader range of infection severities, including individuals with more pronounced symptoms. By contrast, the present sample consisted exclusively of non-hospitalised individuals with self-reported mild COVID-19, a subgroup less likely to experience observable cognitive impairments (Priftis et al., 2022). Furthermore, while those studies used tasks like Go/No-Go and the full BADS battery, the current study relied on brief, isolated subtests—potentially limiting sensitivity to subtle inhibitory deficits.

The choice of EF measures may also play a role in the null findings. The Colour-Word Interference Test, though widely used, may be less sensitive to subtle or transient disruptions in high-functioning, young adults (Adólfsdóttir et al., 2016). Thus, it is plausible that

inhibition-related impairments existed but went undetected due to measurement limitations or insufficient statistical power in the current sample.

Given the differences across studies, further research is needed to determine the effect of COVID-19 on response inhibition. Such research should use longitudinal methods and different assessments to capture the complex effects of COVID-19 on this aspect of executive functioning.

Cognitive Flexibility and Task Switching

Although often associated with moderate or severe illness, increasing evidence indicates that even individuals with mild COVID-19 may experience persistent deficits in flexibility and set-shifting. For instance, García-Sánchez et al. (2022) reported that individuals recovering from moderate COVID-19 demonstrated greater perseverative errors on the Modified Wisconsin Card Sorting Test (M-WCST), highlighting impairments in rule adaptation and feedback processing. Similarly, Becker et al. (2023), in a large sample of outpatient-treated patients, found significantly higher rates of executive dysfunction—including cognitive flexibility deficits—compared to matched non-infected controls.

These findings are consistent with Woo et al. (2020), who reported cognitive inefficiencies in short-term memory and attention among non-hospitalised individuals, and with Henneghan et al. (2022), who found that around 40% of patients with mild illness displayed reduced performance in attentional control and flexibility. These impairments may be driven by neuroinflammatory changes, even in the absence of severe respiratory illness (Radhakrishnan

However, in the present study, no statistically significant group differences were found on the Trail Making Test (TMT) Conditions 2 and 4, both of which assess cognitive flexibility and divided attention. This stands in contrast to several studies using similar or

related instruments. Pallanti et al. (2023), for example, linked elevated inflammatory markers to poorer performance on the D-KEFS TMT in mild cases, while Hampshire et al. (2021) observed large-scale deficits in verbal memory and attention among non-hospitalised patients using an online cognitive platform. The absence of significant group-level differences in the current study may be attributable to several methodological factors.

First and foremost, it is important to consider test sensitivity. The TMT, particularly in high-functioning and younger populations, may be subject to ceiling effects (Tombaugh, 2004), limiting its ability to detect subtle deficits. Indeed, studies that reported post-COVID cognitive impairments often employed more comprehensive or nuanced tasks, such as the M-WCST (Arelis et al., 2025) or full BADS battery (Delgado-Alonso et al., 2022), rather than standalone subtests. This limitation in tool sensitivity may have contributed to the null results observed in this study.

Interestingly, a statistically significant difference was found on the Rule Shift Cards (RSC) task, with the COVID-19 group outperforming the NON-COVID-19 group. While at first glance this may suggest enhanced cognitive flexibility in the COVID-19 group, this interpretation must be treated with some attention. As previously discussed, the result may reflect a statistical artefact—a Type I error—given the number of comparisons conducted and the small sample size (Leppink et al., 2016). Alternatively, non-cognitive factors such as test anxiety, motivation, or familiarity with rule-based reasoning may have differentially impacted performance. Participants in the NON-COVID group may have been more self-conscious or anxious, especially given the study's focus on cognitive evaluation post-pandemic. Given that executive function assessments are highly sensitive to emotional and environmental variables (Lezak et al., 2012), such factors must be considered when interpreting single significant results.

Another possibility is the presence of compensatory mechanisms in the COVID-19 group, whereby individuals may have engaged additional cognitive strategies or neural resources to perform effectively—a phenomenon observed in other post-infection studies (De Paula et al., 2022). However, without neuroimaging or qualitative data, such speculation remains tentative.

The current findings reinforce the notion that isolated significant outcomes in small samples must be interpreted conservatively. Given the heterogeneity in task types, sample characteristics, and analysis strategies across studies (Becker et al., 2023; Arelis et al., 2025), future research should aim to replicate this finding using larger, more demographically balanced samples, and should control for affective and environmental variables, such as fatigue or emotional state during testing, possibly using a questionnaire.

Planning

While planning is less frequently studied in isolation, emerging evidence suggests that individuals with mild COVID-19 may experience planning-related difficulties—particularly when these functions are embedded within broader cognitive domains.

As discussed in Chapter 2, planning is a higher-order executive function that includes evaluating and analysing a series of actions before carrying them out (Diamond, 2013). It also involves the ability to anticipate future situations, objectively evaluate all possibilities, and mentally organise steps in a logical order, relying on impulse control, sustained attention, and memory (Lezak et al., 2012).

Zhao et al. (2022), for example, found no significant planning impairments among individuals recovering from asymptomatic to moderate infections, suggesting that this domain may be relatively spared in mild cases. Similarly, Priftis et al. (2022) found no major deficits in executive performance, including planning, among patients who had been

hospitalised for COVID-19. However, other studies present a more complex picture. De Paula et al. (2022) identified visuo-constructive impairments related to goal-directed tasks, suggesting that deficits in spatial planning may emerge even in non-severe cases. These were linked to neuroinflammatory changes and functional disconnection in frontoparietal networks, implicating the broader circuitry involved in executive functioning.

In the present study, no statistically significant differences were observed between COVID-19 and NON-COVID-19 participants on the Zoo Map subtest, which is designed to assess real-world planning ability. While this finding appears consistent with those of Zhao et al. (2022), it should again be interpreted cautiously. The Zoo Map test, though ecologically valid, may lack sensitivity to mild or transient deficits, particularly in younger or highly educated participants who may reach near-perfect scores due to ceiling effects (Proctor & Zhang, 2008). This concern echoes the findings of Fernandez and Marcopulos (2008), who emphasised the importance of considering educational background and cognitive reserve when assessing EF.

Additional evidence from Hampshire et al. (2021) and De Pádua Serafim et al. (2024) supports the idea that executive domains such as planning and organisation may be impacted even in non-hospitalised populations, particularly through mechanisms of chronic low-grade neuroinflammation. Although not all studies agree on this point, the divergence in the literature could reflect variations in how planning is measured. Studies using brief screeners (e.g., TMT or Digit Span) may underreport impairments that would otherwise appear in more multifaceted or contextualised tasks, such as the Tower of London (Delgado-Alonso et al., 2022).

In light of these methodological considerations, the absence of group differences in planning should be regarded as inconclusive, rather than definitively indicating cognitive

equivalence. Future research would benefit from incorporating multiple measures of planning, including tasks with greater complexity, novelty, and ecological validity, and examining how emotional or contextual factors (e.g., fatigue, motivation) interact with executive demands.

Measurement Sensitivity & Limitations

A critical consideration in interpreting the current study's inconclusive findings lies in the psychometric properties and sensitivity of the executive functioning (EF) assessments used. While the selected tools—the Colour-Word Interference Test (CWIT), Trail Making Test (TMT), Rule Shift Cards (RSC), and Zoo Map Test (ZM)—are widely recognised and clinically validated, they may lack sufficient depth to detect subtle or transient executive deficits, particularly in young, educated, non-hospitalised populations recovering from mild COVID-19.

As explained in Lezak et al. (2012), many standardised neuropsychological tests measure optimal performance under structured, decontextualised conditions, which may fail to capture the adaptive, dynamic nature of real-world executive functioning. This concern is echoed in studies such as Adólfsdóttir et al. (2016) and Fernandez and Marcopulos (2008), who note that younger, highly educated individuals often perform near ceiling on these tasks, particularly on conditions such as TMT Condition 2 or CWIT Condition 1. This leads to restricted score variability and reduced statistical power to detect group differences—an issue that may have contributed to the largely non-significant results in the current study.

Moreover, tools such as the TMT (Conditions 2 and 4) and CWIT (Conditions 3 and 4) rely primarily on speeded performance, which may not fully engage the executive systems implicated in fatigue-sensitive or emotionally complex situations—common complaints among post-COVID populations (Woo et al., 2020; Becker et al., 2023). In contrast, studies

that reported stronger group differences often employed multi-domain assessments or ecologically rich tasks like the Tower of London or modified WCST (Delgado-Alonso et al., 2022; Arelis et al., 2025).

Further Limitations of Neuropsychological Assessments

The limitations of the Zoo Map and RSC tests are also relevant. Although designed to simulate real-world planning and rule-shifting, these tasks are brief and subject to performance inflation in individuals with high cognitive reserve (Stern, 2009). Additionally, the normative benchmarks used for these tests may not fully reflect the sociocultural context of Maltese participants, potentially introducing construct bias (Proctor & Zhang, 2008).

Put together, these variables suggest that the lack of statistically significant findings in many EF domains should be seen as a possible result of low assessment sensitivity, rather than evidence of normal functioning. Future studies may benefit from including longer, more ecologically valid, and affectively engaging assessments, as well as self-report or informant-rated EF measures that can capture day-to-day executive challenges more holistically.

Methodological Complications

The investigation of cognitive functioning in post-COVID-19 populations presents unique methodological challenges that may account for discrepancies between studies, including this study. These issues span sampling methods, self-reported illness characteristics, psychosocial confounds, and a lack of standardisation in defining cognitive outcomes.

First, reliance on self-reported infection status and retrospective symptom descriptions may introduce recall bias, particularly regarding the presence and severity of cognitive symptoms (Woo et al., 2020). In the present study, none of the participants reported hospitalisation, and only one individual endorsed symptoms such as brain fog—possibly

underestimating true symptom prevalence due to memory inaccuracy or social desirability effects.

The clinical heterogeneity of COVID-19 complicates comparisons across studies. As Becker et al. (2023) and Arelis et al. (2025) noted, even among non-hospitalised populations, there is considerable variability in symptom duration, fatigue levels, and post-viral inflammation—all of which may affect cognitive outcomes but were not captured in the current dataset. To date, the majority of studies—including the present one—have not incorporated objective biological measures, such as cytokine profiling or neuroimaging, to investigate the underlying mechanisms of post-COVID cognitive dysfunction. The absence of such data limits our ability to determine whether observed impairments stem from direct neuroinflammatory effects or are secondary to psychosocial or systemic factors.

Moreover, psychological circumstances such as depression, anxiety, and fatigue, which are common following viral illness and during global health crises, further complicate interpretation. For instance, Delgado-Alonso et al. (2022) found that anxiety and sleep dysfunction were associated with poorer EF performance, while others (García-Sánchez et al., 2022) reported no such association—underscoring the inconsistency and methodological splitting of the current literature.

Finally, variation in control group selection—whether matched by age, education, or symptom burden—affects outcome validity. The current study controlled for demographic variables but did not assess psychological state, which may have influenced test performance. These limitations highlight the importance of multifactorial models and integrative designs in future research.

The Role of Age, Education, and Gender

Although the current study did not find statistically significant effects of age, gender, or time since education completion on executive functioning, these variables may still act as moderating factors in post-COVID cognitive outcomes. Research on cognitive resilience suggests that individuals with higher educational attainment or more recent cognitive engagement may experience buffering effects against mild neurological disruption (Stern, 2009). However, these protective factors may also obscure subtle deficits, particularly in structured testing environments. Moreover, age-related cognitive decline typically interacts with viral and metabolic insults over time (Fraser et al., 2022), and the absence of older adults in the present sample limits insight into these dynamics.

Future studies should consider interaction effects between demographic variables and COVID-related cognitive symptoms, particularly through the use of moderated regression models or stratified analyses, which could reveal group-specific vulnerabilities not detectable through basic group comparisons.

Neurocognitive and Executive Vulnerability in Mild COVID-19

Although all participants in the current study experienced only mild, non-hospitalised cases of COVID-19, the executive domains assessed—inhibition, planning, and cognitive flexibility—remain theoretically vulnerable to COVID-19-related neurobiological disruption. A growing body of literature points to mechanisms such as neuroinflammation, microvascular injury, and glial activation that can impact brain function even in the absence of structural damage or severe systemic illness (Aghagoli et al., 2020; Boldrini et al., 2021).

Executive functioning is primarily supported by frontal-subcortical circuits, including the dorsolateral prefrontal cortex, anterior cingulate cortex, and basal ganglia—regions known to be sensitive to metabolic and inflammatory changes (Diamond, 2013). These

circuits facilitate flexible thinking, goal-directed behaviour, and inhibitory control, and are particularly susceptible to low-grade systemic inflammation, which may persist even after mild COVID-19 (Pallanti et al., 2023; Radhakrishnan & Kandasamy, 2022).

Theories such as cognitive reserve (Stern, 2009) offer one explanation for the variability in cognitive outcomes observed across studies. Individuals with higher educational attainment or recent academic engagement may demonstrate greater resilience in the face of neurological disruption, potentially masking the presence of subtle deficits. This could partly explain the lack of statistically significant group differences in the present study, particularly given the sample's overall high educational profile and absence of hospitalised or older adults.

These findings therefore highlight that even in mild cases, COVID-19 may exert neurocognitive effects through indirect pathways. However, these may only become evident under high-demand or emotionally charged tasks—conditions that standardised EF tests may not sufficiently replicate. As such, the absence of observed impairments does not necessarily preclude underlying executive vulnerability in this population.

Conclusion

Overall, while the current findings do not indicate widespread executive dysfunction among non-hospitalised individuals post-COVID-19, they highlight the need for caution in interpreting inconclusive results, since executive function may remain vulnerable in this group, particularly under conditions of emotional stress or fatigue.

Chapter 6: Conclusion

Introduction

This study investigated whether executive functioning (EF) test performance differs between individuals who previously contracted COVID-19 and those who have not. A review of the relevant literature was provided, with particular emphasis on the cognitive effects of COVID-19, executive functioning domains, and the potential influence of illness severity and individual health factors. Group comparisons were conducted to test the study's hypotheses, and the results were interpreted in light of previous research.

The first part of this chapter summarises the key findings of the study, as explored in detail in the discussion (Chapter Five). The following sections outline the study's strengths, limitations, and implications, and conclude with recommendations for future research.

Summary of findings

Two main hypotheses concerning EF were evaluated using an analysis of group differences. Participants were divided into two groups based on self-reported COVID-19 status: those who had previously tested positive and those who had not.

EF performance was assessed using a battery of neuropsychological tasks measuring cognitive flexibility, inhibition, and planning. The results revealed no significant group differences across most EF measures, except for the Rule Shift Cards subtest, where the COVID-19 group outperformed the NON-COVID-19 group.

However, this isolated finding should be interpreted with caution due to the small sample size and exploratory nature of the study. No statistically significant effects were observed in relation to the number of infections or demographic variables. Overall, the study did not find statistical support for the hypothesis that mild COVID-19 infection is associated with long-term impairments in executive functioning.

Strengths of the study

This study examined a critically important and ongoing issue—the cognitive consequences of COVID-19—at a time when the virus's long-term effects are not well established. As more people report persisting symptoms long after the acute phase, researching the influence on executive functioning adds to the growing body of international literature.

The present study explored the cognitive characteristics of non-hospitalised individuals with mild to moderate COVID-19, focusing on executive domains such as inhibition and cognitive flexibility. While no statistically significant impairments were identified in this sample, the use of ecologically valid assessment tools enhances the applicability of the findings to real-world functioning. This design adds to the limited research on cognitive functioning in non-severe cases and provides context-specific data relevant to the Maltese population, where such research remains scarce.

Limitations of the study

One methodological limitation of the study is the relatively small sample size (n = 70), which may have reduced the sensitivity to detect subtle between-group differences. Although sufficient for preliminary comparison, larger samples would allow for more robust statistical analysis and enhance the external validity of the findings.

Another important limitation of this study lies in the potential discrepancy between the participants' perceived and reported cognitive difficulties. While several individuals informally described experiencing cognitive issues—particularly during the infection period—these difficulties were not always reflected in their questionnaire responses. This suggests that participants may lack awareness of the extent of their cognitive changes, or may underreport symptoms due to recall bias or difficulty recognising subtle deficits.

While proficiency in English was necessary to participate, differences in familiarity with test-related or academic language among participants may have affected task comprehension. Executive function assessments often rely on precise instructions and their correct interpretations. Subtle misunderstandings, particularly in inhibition or switching tasks, could compromise performance, not due to cognitive deficits, but due to linguistic complexity. This introduces a potentially confounding variable.

Related on to the previous limitation, although the EF tasks used in this study are internationally recognised and widely validated, they have not been specifically standardised for the Maltese population. This raises concerns about cultural and linguistic relevance, particularly in the absence of locally normed neuropsychological tools.

Finally, the study failed to account for potential confounding variables that could have influenced participants' neuropsychological performance at the time of assessment. Factors such as their mental health state (e.g., depression, anxiety) at the time of the assessment, use of psychoactive medications, sleep difficulties, or substance abuse may have altered EF findings. This limitation may result in performance results that do not accurately represent the participants' EF abilities.

Implications of findings

Although the sample size was limited, the findings contribute preliminary insights into executive functioning in individuals with mild to moderate COVID-19 who were not hospitalised. While statistically significant impairments were not identified across most measures, the use of ecologically valid tests allowed for the examination of cognitive performance in real-world contexts. The implications outlined below are intended to inform both clinical practice and future research, while acknowledging the exploratory nature of the present study.

Clinical implications

Previous research on COVID-19 has primarily focused on individuals with severe illness, particularly those requiring hospitalisation or intensive care. In contrast, less is known about the potential cognitive effects in individuals with mild or moderate illness who remain outside of clinical care settings. Although the current study did not identify significant group differences, anecdotal reports and emerging evidence suggest that some individuals may experience persistent cognitive concerns post-infection. Based on this context, the following recommendations may be considered:

- Individuals recovering from COVID-19 who report ongoing cognitive concerns could benefit from brief cognitive screening, particularly if symptoms persist beyond the acute phase. While not diagnostic, such screening may help differentiate between temporary fatigue and more sustained executive difficulties (Becker et al., 2021).

- Given the absence of hospitalised participants in the current sample, further clinical attention may be warranted for higher-risk groups, such as those who required hospital or ICU care, as they may be more vulnerable to cognitive and executive disruptions (Miskowiak et al., 2021).

- Where cognitive rehabilitation is deemed appropriate, programs incorporating ecologically valid tasks may better reflect the executive demands of everyday life, potentially leading to more functional improvements in real-world settings (Burgess et al., 2006).

Research implications

The current findings, while limited, point to several areas for further investigation. In particular, the lack of statistically significant differences may reflect subtle cognitive effects that require more sensitive research designs or larger samples to detect.As a result, the following research implications should be considered:

- Longitudinal research is recommended to assess whether changes in executive functioning emerge or evolve over time following COVID-19 infection. This is particularly important for individuals who report subjective symptoms or have experienced multiple infections.
- The inclusion of both subjective (self-reported) and objective (performance-based) measures is advised in future studies to capture a fuller picture of post-COVID cognitive functioning and to better account for individual variability.

Further Recommendations

Future research should aim to include more demographically and clinically diverse populations—particularly younger and older individuals, as well as those with more severe or hospitalised cases of COVID-19—to better capture the full range of cognitive outcomes. Larger and more balanced samples will improve statistical power, particularly in comparisons involving multiple infections.

Additionally, expanding the scope of executive function assessments through full neuropsychological batteries (e.g., D-KEFS, BADS) and incorporating tasks targeting domains such as working memory, goal management, and decision-making would provide a more comprehensive evaluation of post-COVID cognitive effects.

Finally, future studies would benefit from integrating biomarkers of neuroinflammation and, where feasible, neuroimaging techniques, to explore potential biological correlates of executive dysfunction and improve mechanistic understanding.

Conclusion

In conclusion, this study aimed to assess executive function performance in individuals who previously contracted COVID-19 compared to those who had not. Although no statistically significant group differences were identified, the findings contribute preliminary insight into executive functioning in non-hospitalised individuals with mild to moderate COVID-19. As the first study of its kind conducted within the Maltese context, it offers a foundation for future research on the cognitive impact of COVID-19 and highlights the value of continued assessment and monitoring of executive functioning in post-COVID populations.

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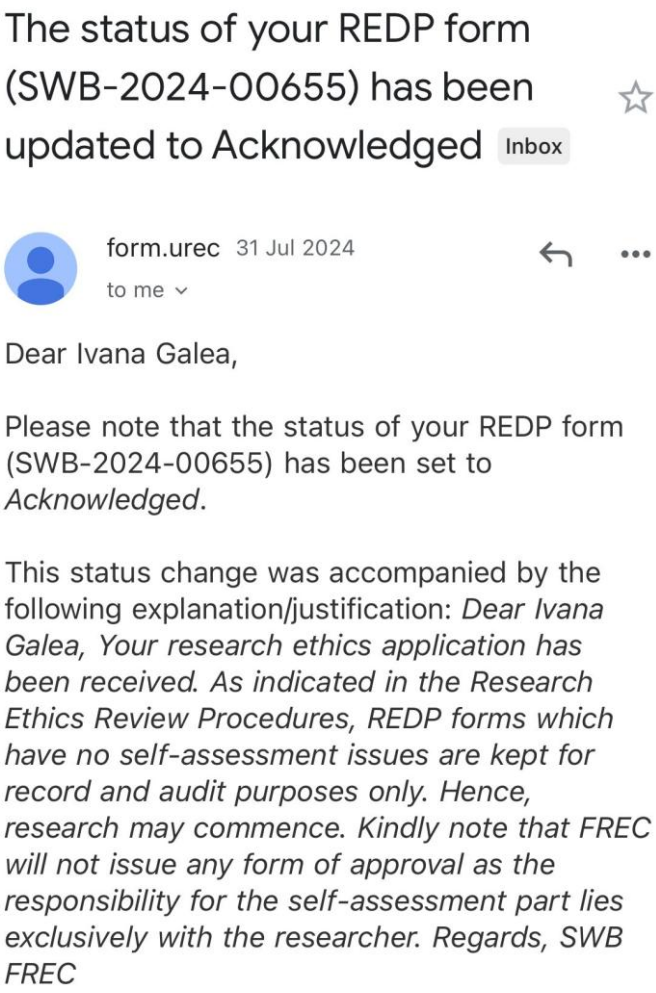
Appendices

Appendix A: Approval from Faculty Research Ethics Committee (FREC)



The status of your REDP form (SWB-2024-00655) has been updated to Acknowledged Inbox

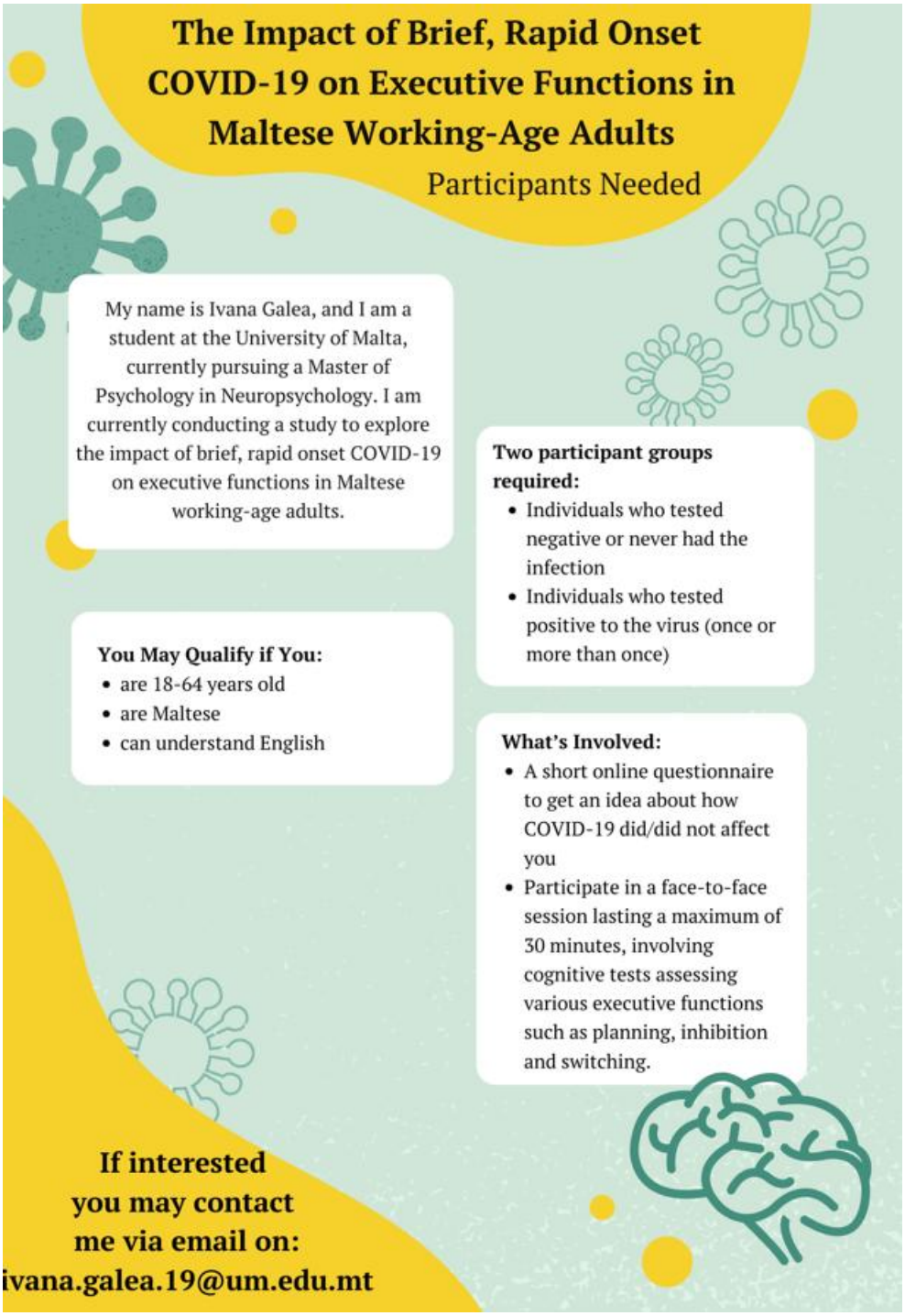
form.urec 31 Jul 2024
to me

Dear Ivana Galea,

Please note that the status of your REDP form (SWB-2024-00655) has been set to *Acknowledged*.

This status change was accompanied by the following explanation/justification: *Dear Ivana Galea, Your research ethics application has been received. As indicated in the Research Ethics Review Procedures, REDP forms which have no self-assessment issues are kept for record and audit purposes only. Hence, research may commence. Kindly note that FREC will not issue any form of approval as the responsibility for the self-assessment part lies exclusively with the researcher. Regards, SWB FREC*

Appendix B: Online poster distributed on social media



Appendix C: Demographic Questionnaire

The Impact of Brief, Rapid Onset COVID-19 on Executive Functions in Maltese Working-Age Adults

Thank you for your interest in participating in this study on the cognitive impact of COVID-19.

This short survey (5-10 minutes) is the first step in exploring how brief, rapid onset COVID-19 may affect cognitive functions such as memory, attention, and decision-making. This form will help us understand your background and schedule the next phase of the study, which includes an in-person assessment.

Your participation is completely voluntary, and you may withdraw at any time without consequences. All data will be anonymized and treated with strict confidentiality, accessible only to the research team, and securely stored.

* Indicates required question

Participant Information

1. Please enter the participant number provided to you in the invitation *

_____

2. Kindly provide your e-mail address for contact purposes *

_____

3. Gender *

Mark only one oval.

- ◯ Male
- ◯ Female
- ◯ Non-binary
- ◯ Prefer not to say
- ◯ Other: _____

4. Please enter your age in years: *

_____

5. Level of education *

Mark only one oval.

- ◯ No formal education
- ◯ Primary education
- ◯ Secondary education
- ◯ Post-secondary education
- ◯ Bachelor's degree
- ◯ Master's degree
- ◯ Doctorate
- ◯ Other: _____

6. How many years ago did you complete your highest level of education? (Please answer in years) *

_____

7. Employment Status *

Mark only one oval.

- ◯ Employed full-time
- ◯ Employed part-time
- ◯ Self-employed
- ◯ Retired *Skip to question 9*
- ◯ Unemployed *Skip to question 9*
- ◯ Student *Skip to question 9*

8. What is your current occupation? *

_____

COVID-19 Experience

9. Have you received an official diagnosis of COVID-19 (that is, confirmed by a PCR test)? *

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to question 19*

COVID-19 Experience

10. How many times were you positive to COVID-19? *

Mark only one oval.

- ◯ Once
- ◯ Twice
- ◯ Three times
- ◯ More than three times

11. Did you require hospitalization due to COVID-19? *

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to question 13*

12. If hospitalized, what interventions were required? (Select all that apply) *

Tick all that apply.

- [ ] Intensive Care Unit stay
- [ ] Mechanical Ventilation
- [ ] Medications (such as steroids, antiviral drugs)
- [ ] Oxygen Therapy
- [ ] Other: _____

Cognitive Difficulties

13. Did you experience any cognitive difficulties during recovery? (e.g., memory issues, difficulty concentrating, brain fog) *

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to question 15*

Cognitive Difficulties

14. Please describe the cognitive difficulties you experienced. *

_____

_____

_____

_____

_____

15. Have you experienced any cognitive difficulties after recovery? *

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to question 19*

Cognitive Difficulties

16. What long-term cognitive challenges are you currently experiencing?

_____

_____

_____

_____

_____

17. Did you have to make any adjustments in your life to deal with these challenges?

Mark only one oval.

- ◯ Yes *Skip to question 18*
- ◯ No *Skip to question 19*

Cognitive Difficulties

18. Please describe the changes.

_____

_____

_____

_____

_____

19. Do you have any of the following conditions? (Select all that apply) *

Tick all that apply.

- [ ] Neurodevelopmental disorders (e.g., autism, ADHD)
- [ ] Epilepsy
- [ ] Psychiatric Conditions (e.g. depression, anxiety)
- [ ] Past head injuries (e.g. concussions, traumatic brain injury)
- [ ] None of the above
- [ ] Other: _____

Consent for Assessment

20. The next part of the study includes an assessment of various cognitive functions. Would you be available for an in-person session?

Mark only one oval.

- ◯ Yes
- ◯ No

21. When are you generally available for the session? (Check all that apply) *

Tick all that apply.

- [ ] Morning
- [ ] Afternoon
- [ ] Evening
- [ ] Weekdays
- [ ] Weekends

Appendix D: Participant Information Sheet

Information letter

Dear Participant,

My name is Ivana Galea, and I am a student at the University of Malta, currently pursuing a Master of Psychology in Neuropsychology. I am conducting a research study for my dissertation titled **"The Impact of Brief, Rapid Onset COVID-19 on Executive Functions in Maltese Working-Age Adults**", supervised by Dr. Kristina Bettenzana. Below, you will find detailed information about the study and what your participation would entail, should you decide to take part.

The aim of my study is to explore the effects of acute COVID-19 on executive functioning, examining the neuropsychological outcomes and differences between individuals who experienced acute COVID-19 and those who tested negative for the infection. Your participation in this study will contribute to a better understanding of the specific effects of the virus on executive functions such as planning, memory, and decision-making, as well as the neuropsychological consequences of brief, rapid onset COVID-19. Any data collected from this research will be used solely for the purposes of this study.

Should you choose to participate, you will be assigned to one of two main groups:

- Group 1: Individuals who tested negative or never had the infection.
- Group 2: Individuals who tested positive

You will be invited to attend an assessment where subtests from the Delis-Kaplan Executive Function System (DKEFS) and the Behavioural Assessment of the Dysexecutive Syndrome (BADS) will be administered. Data collected will be treated confidentially and anonymously. Only myself as the researcher, my supervisor, and examiners will have access to the original data upon request.

Participation in this study is entirely voluntary; in other words, you are free to accept or refuse to participate, without needing to give a reason. You are also free to withdraw from the study at any time, without needing to provide any explanation and without any negative repercussions for you. Should you choose to withdraw, any data collected from your assessment will be deleted one year after submission of the study.

If you choose to participate, please note that there are no direct benefits to you, and your participation does not entail any known or anticipated risks. As a participant, you have the right under the General Data Protection Regulation (GDPR) and national legislation to access, rectify, and where applicable, ask for the data concerning you to be erased. All data collected will be stored in an anonymized form on completion of the study for one year. Should you wish to find out about the final results of this study, please contact me on the email provided below. Kindly note that you will only be provided with a summary of the results from the study, not your personal results.

A copy of this information sheet is provided for your reference. Your contribution to this study would be highly appreciated. If you wish to participate, please contact Ivana Galea on the email listed below. Furthermore, if you have any questions or concerns, please do not hesitate to contact me or my supervisor.

Thank you for your time and consideration.

Sincerely,

Researcher

Ivana Galea

ivana.galea.19@um.edu.mt

Supervisor

Dr Kristina Bettenzana

kristina.vella@um.edu.mt

Appendix E: Participant's Consent Form

Participant's Consent Form

The Impact of Brief, Rapid Onset COVID-19 on Executive Functions in Maltese Working-Age Adults

I, the undersigned, give my consent to take part in the study conducted by Ivana Galea. This consent form specifies the terms of my participation in this research study.

1. I have been given written and/or verbal information about the purpose of the study; I have had the opportunity to ask questions and any questions that I had were answered fully and to my satisfaction.
2. I also understand that I am free to accept to participate, or to refuse or stop participation at any time without giving any reason and without any penalty. In the event that I choose to withdraw from the study, any data collected from me will be erased one year after submission of the study.
3. I understand that I have been invited to undergo assessments using subtests from the Delis-Kaplan Executive Function System (DKEFS) and the Behavioural Assessment of the Dysexecutive Syndrome (BADS). This assessment will take approximately 45 minutes to 1 hour and will be conducted at a place and time convenient for me.
4. I understand that my participation does not entail any known or anticipated risks.
5. I understand that there are no direct benefits to me from participating in this study. However, I understand that this research may benefit others by contributing to a better understanding of the effects of acute COVID-19 on executive functions.
6. I understand that, under the General Data Protection Regulation (GDPR) and national legislation, I have the right to access, rectify, and where applicable, request the erasure of data concerning me.
7. I understand that all data collected will be stored in an anonymized form on completion of the study for 1 year.
8. I have been provided with a copy of the information letter and understand that I will also be given a copy of this consent form.
9. I understand that I will only be provided with a summary of the results, not my personal results, should I request them.
10. I have read and understood the above statements and agree to participate in this study.

Date: _____

Name of participant: _____

Signature: _____

_____

Ivana Galea

ivana.galea.19@um.edu.mt

Appendix F: Explanation of Tukey's Fence and Winsorisation of Outlier

The outlier was examined using Tukey's Fence method, This non-parametric approach identifies outliers based on the interquartile range (IQR), calculated as the difference between the 75th percentile (Q3) and the 25th percentile (Q1). According to Tukey (1977), and further elaborated by Hoaglin, Iglewicz, and Tukey (1986), outliers fall below Q1 – 1.5 × IQR or above Q3 + 1.5 × IQR, while extreme outliers fall beyond 3 × IQR. This method is especially useful in small samples or when normality is broken since it overcomes the constraints of parametric outlier detection strategies based on mean and standard deviation. For the CWIT_3 variable, Q1 and Q3 were identified as 10 and 13, respectively, resulting in an IQR of 3. The lower extreme fence was thus calculated as 10 – (3 × 3) = 1. One participant in the NON-COVID-19 group had a raw CWIT_3 score of 1, placing them at the lower extreme. Although this value was a valid response, it was the only extreme outlier across the dataset and was considered potentially impactful for subsequent analyses. In managing outliers, Tabachnick and Fidell (2013) propose three main strategies: deletion, transformation, and substitution. While deletion is often viewed as the most conservative option, it risks reducing the sample size and potentially undermining statistical power (Mowbray et al., 2019). In this study, Winsorisation was selected as the preferred technique. This method involves replacing the outlier with the closest non-outlier value in the distribution.

Appendix G: Tables of Comparisons within the COVID-19 group

Table 9

Results of comparisons of EF according to gender

Variable	Descriptor	Male (*n=10)*	Female (*n=17)*	Comparison		
		Median	Median	U	*p*	*r*
RCS	Profile Score	4	4	81.0	.810	0.029
ZM	Profile Score	2.5	3	73.0	.523	0.076
CWIT	Condition 1	12	10	74.5	.594	0.064
	Condition 2	11.5	12	79.5	.776	0.034
	Condition 3	12	11	58.0	.166	0.165
	Condition 4	11	12	77.5	.703	0.046
TMT	Condition 2	10	10	59.5	.193	0.156
	Condition 4	10.5	9	73.5	.560	0.070

Note: r = effect size calculated using r= $\frac{Z}{\sqrt{N}}$; RSC= Rule Shift Cards, ZM=Zoo Map, CWIT=Colour Word Interference Test, TMT=Trail Making Test.

Table 10

Results of comparisons of EF across age groups

Variable	Descriptor	18-30 years (*n=18)*	31-61 years (*n=9)*	Comparison		
		Median	Median	U	*p*	*r*
RCS	Profile Score	4	4	72.0	.580	0.066
ZM	Profile Score	2	3	79.0	.913	0.013
CWIT	Condition 1	10	11	66.0	.436	0.093
	Condition 2	12	11	76.5	.812	0.028
	Condition 3	11.5	11.0	81.0	1.000	0.000
	Condition 4	12	11	74.5	.735	0.040
TMT	Condition 2	10	10	72.5	.657	0.053
	Condition 4	9.5	10	74.0	.717	0.043

Note: r = effect size calculated using r= $\frac{Z}{\sqrt{N}}$; RSC= Rule Shift Cards, ZM=Zoo Map, CWIT=Colour Word Interference Test, TMT=Trail Making Test.

Table 11

Results of comparisons of EF across varying COVID-19 infection frequencies

Variable	**Descriptor**	**Once (*n=18)***	**More Than Once (*n=9)***	**Comparison**		
		Median	Median	U	*p*	*r*
RCS	Profile Score	4	4	63.0	.269	0.132
ZM	Profile Score	2.5	3	80.5	.978	0.003
CWIT	Condition 1	10	10	78.5	.897	0.016
	Condition 2	11.5	12	67.5	.475	0.085
	Condition 3	12	11	72.5	.655	0.053
	Condition 4	11.5	12	78.0	.876	0.019
TMT	Condition 2	10	9	63.5	.360	0.109
	Condition 4	10	9	63.5	.364	0.108

Note: r = effect size calculated using $r = \frac{Z}{\sqrt{N}}$; RSC= Rule Shift Cards, ZM=Zoo Map, CWIT=Colour Word Interference Test, TMT=Trail Making Test.

Table 12

Results of comparisons of EF according to years of completion of highest level of education

Variable	**Descriptor**	**≤ 10 years since completion (*n=21)***	**> 10 years since completion (*n=6)***	**Comparison**		
		Median	Median	U	*p*	*r*
RCS	Profile Score	4	3.5	52.5	.464	0.087
ZM	Profile Score	3	2.5	45.0	.266	0.133
CWIT	Condition 1	10	11	48.0	.408	0.106
	Condition 2	12	12	42.5	.239	0.147
	Condition 3	11	11.5	60.0	.858	0.021
	Condition 4	12	11.5	56.5	.701	0.046
TMT	Condition 2	10	9.5	44.5	.272	0.131
	Condition 4	9	10.5	58.0	.769	0.035

Note: r = effect size calculated using r= $\frac{Z}{\sqrt{N}}$; RSC= Rule Shift Cards, ZM=Zoo Map, CWIT=Colour Word Interference Test, TMT=Trail Making Test.