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An exploration of executive function, its theoretical construction, and challenges encountered in its understanding and measurement: Did neuropsychology get this right?

Section A: Reworking our understanding of executive function: A narrative review of cognitive models and their implications for its construction and capabilities.

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Section B: Deconstructing executive function: An investigation into the language and measures used to capture this elusive construct.

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Last but by no means least, thank you to my husband, and my family, for your patience, support, and reminding me to never give up!

Summary of the Major Research Project

Section A argued for the importance of cognitive models in providing a theoretical foundation for complex neuropsychological constructs such as ‘executive function’ (EF). It consisted of a narrative review of 29 existing cognitive models of EF, which were reviewed, critiqued, and then integrated into a novel, unified model of EF. This unified account brought together the affective, motivational and attentional processes involved in goal-driven behaviour. Clinical implications were discussed, alongside recommendations for future research in this area.

Section B applied a content analysis to systematically examine the ways that EF is described, explained and understood by currently available neuropsychological assessment measures and textbooks, and evaluate these in accordance with current evidence on EF. A total of 29 texts were included. Categories were derived from the current evidence base, including the ‘unified model’ of EF presented in Section A, as well as inductively from the texts. Results suggested that the majority of assessments and textbooks were unlikely to provide such an integrated account, however, there were exceptions. New leads for further theoretical development, and clinical implications were discussed.

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Abstract

Executive functions (EF) represent the most fundamental ability of humankind: that to apply free will, through purposeful, goal-driven behaviour. However, beyond their generic characterisation, agreement over a precise definition of EF, and the specific cognitive processes involved, has remained elusive. This review firstly acknowledges the theoretical pitfalls in this area, and argues for the importance of cognitive theories as representing falsifiable hypotheses which can then be assessed against behavioural and neuroimaging data. It then presents a narrative review of cognitive models of EF. Twenty-nine sources, representing 29 cognitive models of EF, were included. These were reviewed, critiqued and findings integrated within a preliminary unified model which accounts for the affective, motivational and attentional processes involved in goal-driven behaviour. Clinical implications are discussed, alongside recommendations for future research in this area.

Keywords: executive function, goal-driven behaviour, cognitive model, narrative review, theoretical development

Introduction

Background

Understanding that ‘true’ freedom for human beings must involve some inhibition of automatic response (or the dissolution of prior conditioning; Krishnamurti, 1954/2001; Sarmah, 2014; van Schie et al., 2022), and the ability to foresee and bring about consequences for oneself and others (Lewis, 1940), positions so-called ‘executive functions’ in the hot seat, worthy of attention for developing our understanding of humanity’s unique capacity to self-direct. ‘Executive functions’ have been associated with subjective wellbeing (Toh et al., 2020), intellect and academic attainment (Engelhardt et al., 2016; Jacob & Parkinson, 2015), and social, occupational and economic functioning (Barkley, 2012): in short, almost every valued aspect of daily life (Diamond, 2013).

‘Executive function’ (EF) is commonly defined as comprising the ‘higher order’ cognitive processes facilitating purposeful, goal-driven behaviour (Barkley, 2012), such as planning, maintaining mental representations (of the desired goal), and self-monitoring (Lezak et al., 2012; Welsh & Pennington, 1988). In essence, EF aligns motivation, intention and action. Any disturbance to, or impairment of EF, can have devastating consequences for an individual’s ability to exercise their own volition, and adapt their behaviour to contextual cues (McDonald et al., 2002). However, beyond this generic characterisation, agreement over a precise definition of EF (and the specific processes which it entails) has remained elusive. This is an issue that has often gone unmentioned in the literature, perhaps treated ‘as if resolved’ given that it has been subject to ‘160+ years’ of efforts to research the prefrontal cortex (PFC) (p. 4, Barkley, 2012). Nevertheless, the lack of confidence with regards to which psychological processes are ‘executive’, and which are not, has had serious implications for theoretical understanding in this area, as well as clinical assessment and intervention. A clear, coherent theoretical model of EF is a necessary step to taking research forward in this area (Barkley, 2012; Chan et al., 2008).

Historical overview

Earlier models of EF were, in the main, based upon observations of individuals with frontal lobe damage, with Luria (1966) first describing difficulties shared amongst a group of individuals with similarly localised injuries (Goldstein et al., 2014). Later models tended to reflect information-processing representations of EF, while more recent have drawn from organic, socially defined processes (e.g., Barkley, 2012).

With his influential ‘systems’ theory, Luria (1973) suggested a distinction between systems of programming/regulation, and implementation, that rely on distinct neural networks (i.e., within the PFC, and from the PFC to more posterior areas; Shallice & Cipolotti, 2018). This ‘dual system’ approach has been drawn on since by researchers. Shiffrin and Schneider (1977) distinguished the roles of ‘automatic’ versus ‘controlled’ processing, suggesting that automatic processing happens when an individual engages in a previously learned sequence of events (e.g., for an experienced driver, co-ordinating driving a car), that no longer requires conscious attention. However, controlled processing occurs when an individual undertakes tasks requiring effortful and conscious control (e.g., navigating an unfamiliar environment, problem-solving). Controlled processing therefore requires the individual’s ongoing attention. However, with practice, controlled processing can become automatic over time, and therefore require a reduced cognitive load (Shiffrin & Schneider, 1977; Goldstein et al., 2014). Thus, the role of attention (specifically, selective attention) was strongly implicated in successful performance on controlled processing tasks. Posner and Snyder (1975) further suggested that ‘cognitive control’ (considered analogous to EF; Miller

& Cohen, 2001) ‘guides’ the processes of selection and suppression of thoughts and emotions relevant (or irrelevant) to future goals.

Norman and Shallice (1986) argued that these distinct processes may reflect the differential activation of existing schemata (previously learned sequences of thought and action) according to situational demands (termed *contention scheduling*, Norman & Shallice, 1986; Friedenberg & Silverman, 2010). A ‘supervisory attention system’ (SAS) was suggested to control contention scheduling (i.e., selecting relevant and suppressing irrelevant schemata; Ramos-Cejudo & Schmitz, 2013) and, in the event that no relevant schemata are found for a given situation, produce a new schema. The SAS has also been considered synonymous with the ‘central executive’ in working memory (Baddeley & Hitch, 1974; Baddeley, 1990).

Since the introduction and increasingly widespread use of functional magnetic resonance imaging (fMRI) in neuropsychological research (Ellis et al., 2020), more attention has been given to how these conceptualisations of EF may be functionally realised in the brain. The focus on hierarchical feedback models (e.g., Baddeley, 1996; Stuss & Benson, 1986), which emphasise the role of EF in the implementation of ‘top-down’ control, shifted towards more dynamic conceptualisations (Monsell & Driver, 2000; Pessiglioni et al., 2018), taking into account observations of multiply activated cortical networks and the nuances of motivational salience. However, in the ensuing enthusiasm for neuroreductionism (Jacobson, 1993), the theoretical grounding for EF has risked getting somewhat lost (Barkley, 2012).

Problems with defining executive functions

The term of ‘executive’ function (EF) was first introduced by Pribram (1973) to capture the functions of the PFC: ‘the executive programmes…necessary to maintain brain organization’

(p. 301, Pribram, 1973). While evidence suggests that neural networks within the PFC may indeed be instrumental in self-direction, via the selection and maintenance of mental representations (i.e., holding goals in mind; Goldman-Rakic, 2002), it also connects with various other regions in the brain (e.g., the limbic system; Feller et al., 2020), suggesting that the PFC may also be recruited for cognitive processes which should perhaps not be considered EF (Alvarez & Emory, 2006; Barkley, 2012; Stuss & Alexander, 2000). Additionally, the multifactorial nature of tasks requiring EF are likely to activate multiple areas within the brain, as well as different regions within the frontal lobe (Stuss & Alexander, 2000). Furthermore, unlike other cognitive functions (e.g., facial processing and facial recognition; Bruce & Young, 1986), many EF-related abilities do not appear to 'doubly dissociate' (i.e., appear absent only in the event of a specific, localised lesion in the brain). This understandably makes localising, and elucidating the concept of EF, an exceptionally challenging task for researchers (Burgess, 1997; Fodor, 1983).

To further illustrate the point, in 2011, a literature review of 60 (of the most frequently cited) studies in the field, found reference to 68 'subcomponents' of EF (including constructs such as intentionality, inhibition, information-processing, self-regulation, and decision-making; Packwood et al., 2011). The reviewers condensed this list to 18, on the basis of semantic and psychometric overlap between the terms. However, they speculated that there may be some confusion between EF, and the specific behaviours observed (or not) when individuals are completing EF-related tasks. For example, 'inhibition' may be a desired behavioural outcome of a decision-making process, rather than itself being a 'subcomponent' of EF (MacLeod et al., 2003; Werner et al., 2022). Furthermore, despite appearing ostensibly different, some hypothetical executive behaviours can nevertheless be achieved through identical behavioural means (e.g., 'inhibition', 'planning' and 'control'; Rabbitt, 1997). On this note, Packwood et al. (2011) called for greater parsimony in use of terminology around

EF. This is likely to need some ‘rethinking’ of how EF is conceptualised, and the various processes attributed to it (Barkley, 2012; Packwood et al., 2011; Werner et al., 2022).

Clinical implications

Alongside problems in the theoretical domain, there has been growing recognition of the clinical need to understand, and rehabilitate this group of functions (Burgess, 1997). As well as deficits in ‘higher order’ cognitive processes (i.e., those enabling purposeful and adaptive responding; McDonald et al., 2002), individuals with impaired EF may also struggle with emotional-behavioural difficulties: a decreased ability to empathise (Hsieh et al., 2013; Yan et al., 2020), and inappropriate social behaviour (Grafman & Litman, 1999; Strauss et al., 2006). These difficulties are linked to increased caregiver burden and depression (Martinez et al., 2018). Deficits in EF have also been connected with offending behaviour and recidivism (Meijers et al., 2015), a burgeoning area of research which also highlights the significant societal burden associated with compromised EF (Olgilvie et al., 2011). Perhaps of greater importance, however, are findings suggesting a positive association between EF and the individual’s perceived power of influence (e.g., Smith et al., 2008; Wong & Yang, 2022). These prompt further questions around the developmental interactions between environmental and biological factors in shaping EF (and whether measures of EF are, or should be, taking into account socioeconomic variables); but may also suggest its receptivity to external intervention.

Many cognitive (performance-based) assessments of EF have been developed, to help quantify an individual’s EF abilities, and identify more precisely where their difficulties may lie. However, these measures have frequently been found lacking in ecological and predictive validity: with an individual’s score on one assessment not necessarily predicting performance on others, or reflecting difficulties experienced in real-life (Barkley & Murphy, 2010; Burgess et al., 1998; Chan et al., 2008; Parsons et al., 2017; Sbordone, 2001). This raises doubt as to whether these assessments are, in fact, all measuring EF (Barkley, 2012). Furthermore, they may be compounding the original problem, by connecting presumed EF-related deficits to individuals' psychological and behavioural presentations, with an insufficient understanding of how 'uncompromised' EF may operate in the first instance. Inaccurate 'diagnoses' are likely to lead to inappropriate interventions, which could then affect individuals' prospects for rehabilitation and recovery. Level of EF is considered a key prognostic indicator (Hanks et al., 1999; Park et al., 2015; Poulin et al., 2015; Shea-Shumsky et al., 2019). Therefore, despite issues with their validity, findings from these assessments are likely to have a significant impact on the hopes and expectations of clinicians, and their clients.

Theoretical considerations

'Neuropsychology' is the study of brain-behaviour *relationships* (p. 59, Barkley, 2012). Therefore, it is important to be mindful of the potential for error in conflating neural activity with psychological phenomena (e.g., assuming an increase in cerebral activity is equal to an individual's 'intention to act', as in Libet et al., 1983; Scruton, 2012), when these are only known to be two co-occurring events. It is the individual, the person, who holds intention, foresees consequences, and feels joy and pain; the brain itself does not 'think' or 'feel', but demonstrates excitation *when* the individual is thinking (Bennett & Hacker, 2003). There is also no reason why thoughts should necessarily reflect neuronic traits (e.g., excitatory or inhibitory impulses; MacLeod et al., 2003). Understanding the mechanisms involved in EF, therefore, requires the integration of both top-down and bottom-up approaches (respectively associated with cognitive psychology and neuroscience; Churchland, 1986) in theory-building. There is a need to firstly develop a cognitive model of EF, with testable hypotheses (Barkley, 2012). It can then be investigated whether or not the hypothesised model can be supported by neuroimaging research (Simon & Newell, 1971). Any amendments can then be considered, and new hypotheses recommended, until a general consensus evolves on the likely construct of EF and its realisation in the brain.

It is important to remain conscious of the objectives of theory-building. The field of neuroscience has been criticised for 'forgetting the questions' that it attempts to answer (Bennett & Hacker, 2003; Scruton, 2012); indeed, why should an understanding of neural architecture matter, unless it adds something to our current understanding of the human condition? To bring cold, computational models to life, the reality of their implications on human lives (their psychological wellbeing, and everyday functioning) must also be explored (Sacks, 1985).

Objectives

To best capture the 'nature' of EF required firstly a review of existing cognitive models. The review drew from the extant literature to form a coherent theory of how EF may be constructed, and hypothesise a framework through which it might be possible to evaluate the qualities of EF definitions and assessments still circulating in practice. Several authors have commented on the need for greater integration of cognitive psychology and neuroscience research in investigating EF (e.g., Harlé et al., 2013; Kurzban et al., 2013); this review also aimed to provide a platform from which this could be taken forward.

To the author's knowledge, no such review has been carried out on the cognitive modelling of EF. A review was completed by Tirapu-Ustarroz et al. (2017, in Spanish) on factorial models of ‘attention and executive control’. However, at the time of writing, this was not accessible in English, although there was no suggestion that the authors went beyond factorial analysis to consider EF-related variables at a more critical, semantic level. Other shorter and historical overviews have been helpfully provided (e.g., Goldstein et al., 2014; Barkley, 2012). Existing reviews on the construction of EF have, by and large, focused on neural substrates (e.g., Alvarez & Emory, 2006; Friedman & Miyake, 2017; Friedman & Robbins, 2022). As argued previously, these may risk ‘jumping the starting gun’ while conceptual issues remain unclarified. This does not in itself diminish the potential of their findings, but may come to undermine the validity of the questions they are attempting to answer (Bennett & Hacker, 2003). For example, attempting to identify ‘EF-relevant’ neural networks, by observing their activation while an individual performs an ‘EF-relevant’ task, and then to discover that the task lacks both construct and ecological validity, does not necessarily deem the neurological observations irrelevant to EF; but such observations are insufficient in providing answers about EF.

The specific objectives of this review were to:

- Identify texts which attempt to conceptualise, or comprehend EF and present a cognitive model of how these processes may be realised;
- Review and critique these texts with reference to the current literature;
- Integrate findings into a single, unified model of EF, which may then be available for further scrutiny against information from clinical and neuroimaging research.

Method

Eligibility criteria

This review included all original published articles and book chapters, which attempted to theorise EF as a cognitive model (i.e., provided a ‘reason-giving’ account that hypothesised relationships between variables and attempted to make sense of them; Ogrinc et al., 2016), and were available in English. The work may have taken an inductive approach, making sense of specific findings by integrating these into a model; or a deductive approach, hypothesising based on existing neuropsychological theory. Attempts by the work to then ‘map’ these processes to corresponding brain structures and neural activity were not considered necessary for inclusion.

The searches were restricted to articles/chapters published since 2001. This was to take into account developments in the literature following publication of the clinical assessment of EF, the Delis-Kaplan Executive Function System (DKEFS; Delis et al., 2001). The authors of the DKEFS noted that many extant tests of EF were developed in the 1940s, and aimed to integrate these with the knowledge also accrued over the past 60 years to develop a new assessment tool (Homack et al., 2005). The DKEFS was argued to represent an important development in assessments of EF, particularly due to its empirical differentiation of performance indicating deficits in ‘lower’ or ‘higher-level’ cognitive processing (Homack et al., 2005; Swanson, 2005). The widespread use and popularity of the DKEFS (Keifer & Tranel, 2013) render its publication an important event for research in this area, for its impact on the collective thinking of neuropsychologists around EF in the 21st century. Articles/chapters published since this date were thus considered likely to have incorporated developments in the literature up to 2001, and reflect contemporary neuropsychological thinking on the composition of EF.

The aim of the current review was to construct a model of EF, as it may exist when fully developed and intact. Given the complex array of cognitive and affective processes argued to constitute EF, articles/chapters with a narrower focus (e.g., ‘updating’ in working memory) were included only if they also provided an account of how this ‘constituent’ part might contribute to goal-directed behaviour. Any original studies may have included adult participants (≥18 years old), with or without an acquired brain injury/neurodegenerative illness (as the experiences of those with disruption to their executive capabilities can also provide valuable insights into the ‘construction’ of EF). However, studies with a particular focus on the effect of other psychiatric diagnoses (e.g., depression or schizophrenia) on EF (or vice versa: the effects of EF on mental health difficulties), were excluded. Developmental models of cognition (which either implicitly or explicitly pertained to aspects of EF, e.g., Piaget, 1950/2001), and those with an emphasis on EF in ‘neurodiverse’ presentations (e.g., in autism or ADHD) were also excluded.

Sources of information

Book chapters, and articles published in peer-reviewed journals were retrieved from the electronic databases PsycINFO and Pubmed/Medline. At a later stage of the screening process, any further relevant articles/book chapters were identified from the reference lists of articles obtained in full text (see *Data collection*). For example, if a previously existing cognitive model was cited by an article (and was not already included), efforts would be made to retrieve the original citation for the model.

Search strategy

Given that multiple terms are used in referring to EF, broad search terms were used to maximise sensitivity in retrieving relevant articles/chapters. The searches were conducted using combinations of the following terms: ‘executive function/s’, ‘cognitive control’, ‘frontal functions’, ‘attentional system’, ‘model’ and ‘theory’. ‘Executive function/s’, ‘cognitive control’, ‘frontal functions’ and ‘attentional system’ were searched for as keywords in the title, whereas ‘model’, and ‘theory’ were searched for as keywords in the abstract.

‘Executive function/s’ and ‘frontal functions’ were selected as commonly used terms for the construct of interest. The terms ‘cognitive control’ and ‘attentional system’ were used to ensure that the search went beyond articles/chapters with a primary focus on neuroanatomical correlates of EF (as may have been disproportionately targeted by using only neuropsychological labels), and also included work looking into how it might be conceptualised cognitively. ‘Model’ and ‘theory’ were the terms considered to best capture what was being sought: a progressive idea of how a system may function, that enables the set of abilities known as EF.

Data collection

The data collection process had five stages, incorporating recommendations by PRISMA guidelines (see Figure 1; Page et al., 2021). One reviewer (KA) carried out the searches for the identification of records, using pre-specified search terms. All duplications were removed. Retrieved titles and abstracts were screened for eligibility. An external postgraduate reviewer screened 5% of retrieved titles/articles to ensure consistency of application of eligibility criteria. There was substantial agreement between the reviewers on eligibility (Cohen’s Kappa = 0.76, $p < .001$; Cohen, 1960), with any disagreement resolved through discussion. Any articles/chapters considered relevant were retrieved in full text. The first reviewer then independently assessed eligibility of the retrieved texts. At this point, further relevant citations were sourced from reference lists. Any excluded texts were reported, with reasons given, leaving a final pool of texts for inclusion in the review.

Data extraction and quality assessment

The texts were subject to a textual narrative synthesis, whereby the main findings were summarised, contextualised and compared (Barnett-Page & Thomas, 2009). The following details were extracted: date, author/s, and their cognitive conceptualisation of EF (see Table 1). For any original studies, quality was assessed on dimensions of internal and external validity (using an adapted tabular version of the Revised Standards for Quality Reporting Excellence [SQUIRE], Ogrinc et al., 2016; see Table 2). These included the provision of a theoretical rationale, contextual information (i.e., the key features of the environment in which the study/intervention was carried out), participant information (i.e., generalisability of the sample to the population of interest), information pertaining to measures used (i.e., operational definitions, reliability, construct validity and ecological validity) and control of extraneous variables.

Results

Text characteristics

A total of 29 texts were included in the review (including 16 texts from the original search, and 13 texts from subsequently retrieved citations). Of these texts, five were book chapters, four were reviews, nine used mixed methods approaches (incorporating a review section, analysis of data from previous studies and mathematical/computer modelling), 10 were original studies, and one was a perspective article. Participants in studies included healthy controls (e.g., university students, young adults aged between 18-25, young-old adults aged 65-75), and older adults with early-stage dementia.

Figure 1

PRISMA Flow Diagram

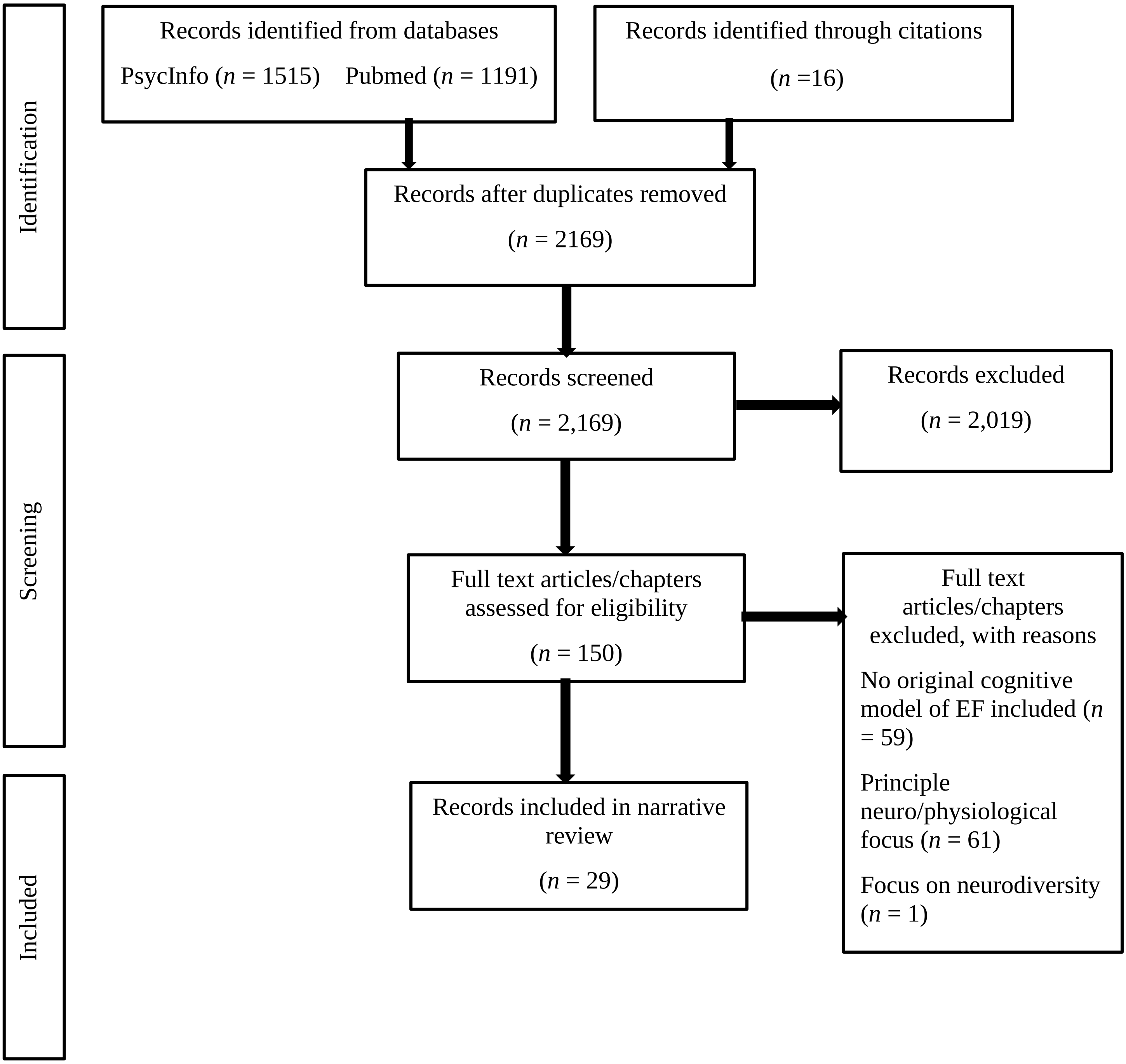


Table 1

Cognitive models of executive functioning

Author(s) / Model	**Date**	**Text**	**Hypotheses**
Botvinick et al. 'Conflict monitoring hypothesis'	(2001)	Mixed methods	Botvinick et al.'s 'conflict monitoring hypothesis' (CMT) sought to account for why, and when, cognitive control processes are recruited. The main premise of CMT is that cognitive control is required when conflict is identified between concurrent processes. When conflict is detected via a conflict monitoring system, EF are deployed to regulate the conflict (e.g., attentional processes used to override automatic but inappropriate responses on Stroop-based tasks).
Braver et al. 'Contextual representations'	(2001)	Cross-sectional study	Braver et al. (2001) hypothesised that age-related deficits in cognitive control (i.e., the pattern of cognitive decline across selective attention, suppression of irrelevant information and working memory) may reflect a depleted ability to maintain and update 'contextual representations'. Braver et al. (2001) suggested that 'contextual representations' were similar to goal representations (which influence planning and behaviour), but which are likely to occur earlier in attentional/interpretive processing (e.g., task instructions, a particular intended action).
Meiran & Gotler 'Task-switching'	(2001)	Cross-sectional study	Meiran and Gotler (2001) found that old age was associated with an increased response time for task-switching, with a pronounced effect for response selection and initiation. A distinction appeared between executive strategies for older and younger participants: with older participants appearing to have an increased tendency to utilise their immediate past experience (i.e., adjusting their response based on the preceding trial), which was advantageous in the single-trial conditions, but not the mixed-trial conditions. Younger

			participants demonstrated a generally faster response selection process, which Meiran and Gotler suggested compensated for their lesser reliance on preceding trials.
Baddeley 'The central executive'	(2002)	Book chapter	Baddeley (2002) reported on attempts to fractionate the 'central executive' component of Baddeley and Hitch's (1974) influential working memory model (WM). Baddeley (2002) argued that its abilities were in the realm of attentional control, necessarily including: focusing attention in the presence of distracting information, dual task control (i.e., multi-tasking) and switching attention from one task to another. Another component of WM was also introduced, the episodic buffer, to account for the capacity for multisensory integration of information (including retrieval of information from long-term memory (LTM)) via conscious awareness. The episodic buffer was conceptualised as a 'global workspace' (Baddeley, 2000).
Gilbert & Shallice 'Parallel distributed processing model'	(2002)	Mixed methods	Gilbert and Shallice's 'parallel distributed processing model' (PDP) drew from earlier models (e.g., Cohen et al., 1990) of the Stroop task (as developed by Stroop, 1935), but with modifications to help account for the range of findings associated with 'normal' performance. Gilbert and Shallice (2002) proposed two pathways (one for word-reading, one for colour-naming), where stronger connections exist for the word-reading pathway (accounting for the general bias towards better performance on this task amongst healthy subjects). 'Task demand units' send a positive or negative (inhibitory) signal to each pathway, depending on which task demand is activated. For example, in a colour-naming task, an negative task demand is issued to the word-reading pathway, while the colour-naming pathway is activated. Furthermore, Gilbert and Shallice (2002) suggested that each new trial begins with a reduction (or 'squashing', p. 307) of the activation of task demand units, to avoid perseverative behaviour. Improvement in performance takes place gradually via Hebbian learning.

Gray & Braver ‘Dynamic goal management’	(2002)	Book chapter	Gray and Braver (2002) hypothesised that emotional influence on cognitive control can be selective (i.e., influencing some aspects of cognitive control and not others). In particular, distinguishing the effects of *approach* vs. *withdrawal* motivation (i.e., to approach appetitive stimuli, and withdraw from aversive stimuli; Spielberg et al., 2008). They argued that approach and withdrawal motivational states selectively regulate goals maintained in WM. With multiple, simultaneously active goals, a critical function of withdrawal motivational states might be to act as a counterbalance, to prioritise certain goals over others when it is important to do so. What gives rise to these opposing motivational states might be current events, recollections from memory or even fantasies.
Engle & Kane ‘Two-factor model’	(2004)	Book chapter	Engle and Kane (2004) suggested that working memory capacity (WMC) may represent ‘executive attention’, defining it more precisely as the ability to maintain stimulus/response cues in active memory, especially in the presence of distracting information. They suggested a ‘two-factor model’ by which individual differences in executive attention may result in performance differences: firstly, a system to maintain information in active memory, and secondly, to resolve conflict between task-appropriate responses, and proactively intended but inappropriate task responses.
Lavie et al. ‘Load theory of selective attention and cognitive control’	(2004)	Cross-sectional study	Goal-directed behaviour involves being able to ignore irrelevant/distracting information. Lavie et al. (2004) distinguished between two mechanisms of selective attention: one, a ‘passive’ process, in which higher perceptual load (i.e., increased number or complexity of perceptual operations required; Lavie & de Fockert, 2003) results in decreased distractor perception; and the second, a process of cognitive control (considered a function of working memory) which reduces interference from distracting stimuli, as long as it has sufficient resource available to maintain attention to the target (i.e., in situations of lower cognitive load).

Braver et al. 'Proactive and reactive control'	(2005)	Cross-sectional study	Building on earlier work (Braver et al., 2001), Braver et al. (2005) distinguished between two forms of cognitive control: proactive, and reactive. 'Proactive control' refers to the sustained maintenance of contextual and goal-related information that enables *optimal configuration* of working memory to respond to incoming information. 'Reactive control' is considered a later 'correction mechanism', involving the reactivation or retrieval of contextual information needed to respond where there is no predictive information available, or the information provided is unreliable. Braver et al. (2005) observed that older adults appeared to rely more on 'reactive control', with less 'proactive bias' than younger adults.
Hester & Garavan 'Effect of salience of items in WM'	(2005)	Cross-sectional study	Hester and Garavan (2005) extended Engle and Kane's (2004) model by demonstrating that both capacity *and* contents of WM can influence attentional control. When participants were required to switch from a primary to a secondary decision-making task, response times were significantly longer for those who were presented with information which had been rehearsed for the primary task. Hester and Garavan (2005) suggested that the items already rehearsed in WM had greater salience than unrelated distractor items, and therefore, were likely to command more attention than the distractor items. They suggested that this effect was similar to that of priming, which also appears to result in a greater level of control being required to attend to the target stimuli (e.g., Farah, 1989).
Mozer et al. 'Sequential dependencies'	(2007)	Mixed methods	Mozer et al. (2007) emphasised the role of cognitive control in terms of constructing a predictive model of the environment and using this model to optimize future performance (i.e., via a proactive control system similar to that advocated by Braver et al., 2005). Mozer et al. (2007) also proposed an additional mechanism of cognitive control, a determinant of how long to wait, following stimulus onset, before producing a response.

			Mozer et al. (2007) considered the effect of 'sequential dependencies' (i.e., the effect of repeated performance of a task on later performance on the same task) in informing cognitive control, arguing that sequential dependencies reflect ongoing adaptation to a continuous stream of experience.
Altman & Gray 'Cognitive control model'	(2008)	Mixed methods	Altman and Gray (2008) introduced their version of a cognitive control model, with the premise that proactive interference from older 'task codes' (i.e., representations of previous task cues) in episodic memory can constrain cognitive control in task switching. Altman and Gray (2008) also described the processes of encoding, retrieval, decay, interference, priming and selective attention as operating alongside eachother in a mutually dependent fashion (so that they constrain eachother, rather than each process functioning independently).
Han & Kim 'Temporal aspects of tasks in facilitating EF'	(2009)	Cross-sectional study	Han and Kim (2009) suggested that cognitive control is utilised in tasks of increased perceptual difficulty, if there is sufficient time available for cognitive control to be implemented (relevance of timing was hypothesised to be able to facilitate *reconfiguration* of a response template relevant to the task).
Gable & Harmon-Jones 'Motivational dimensional	(2010)	Mixed methods	Gable and Harmon-Jones addressed the important issue of affect and motivation: in particular, distinguishing between the effects of high-approach/withdrawal motivation and low-approach/withdraw motivation on cognitive control. Their model postulates that higher motivational intensity (of either positive or negative affect, approach or withdrawal) narrows attentional focus, whereas lower approach motivation broadens attentional focus.

model of affect’			
Barkley ‘Extended phenotype model’	(2012)	Book chapter	Barkley (2012) argued that EF can be construed as an extended phenotype, determined by environmental and genetic factors, and having evolved from overt to covert (private) self-regulation strategies, to optimise performance and others’ perception of oneself in a social group (Barkley, 2001). Barkley suggested that EF refers to self-regulation processes including emotional regulation, working memory (planning, problem-solving, and interference control) and self-motivation, as means of achieving goals. Barkley (2012) highlighted the subjective nature of the utility and value attached to goals, arguing that this was also dependent on the individual’s level of dissatisfaction at failure in obtaining the goal.
Hockey ‘Compensatory control model of fatigue’	(2011)	Book chapter	Hockey (2011) addressed the important issue of fatigue and its effects on motivation and cognitive control. Hockey’s conceptualisation of fatigue is as a state resulting from the extended use of cognitive control strategies. Effortful control (in goal-directed behaviour) is monitored via an ‘effort monitor’ (hypothesised to be part of the central executive in WM), which detects strain present in performance. The effort monitor implements either one of two outcomes: one, to maintain current effort level (with cost to performance); or two, to increase effort level (with cost to internal resources). The first option also provides the option of the original goal being displaced by a competing goal (e.g., rest, or a goal with fewer cognitive demands).
Kopp	(2012)	Perspective article	Kopp (2012) proposed a more parsimonious theory of EF, using Miller et al.’s (1960) concept of ‘test-operate-test-exit’ (TOTE) units (i.e., the action of testing out a particular environmental state and, if a specified condition/goal is not met, executing a specific operation until the condition/goal is met). Kopp suggested that cognitive control may be represented as a hierarchical structure of self-terminating operating

‘Hierarchical recursive system’			units. The example of an individual with a ‘distinct prefrontal syndrome’ of apathy, was considered to potentially reflect a disconnection within the TOTE framework, between motivation and execution of relevant behaviours.
Kruglanski et al. ‘Cognitive energetics theory’	(2012)	Mixed methods	Kruglanski et al. (2012) returned to the issue of motivation for purposeful, goal-oriented behaviour. They suggested that motivation involves both a *driving* and an oppositional *restraining* force, and distinguished between *potential* driving force (the effort an individual is prepared to invest in goal attainment), and *effective* driving force (effort actually invested in goal attainment).
Marien et al. ‘Unconscious routes to executive control’	(2012)	Cross-sectional study	Marien et al. (2012) suggested that unconsciously activated goal-related information could occupy executive attention (i.e., WMC), thus impairing performance on unrelated tasks (i.e., the unconsciously activated goals rendered less cognitive load available for use in pursuit of the other tasks). This is not accompanied by conscious awareness of the goal, nor greater perceived effort. Marien et al.’s findings suggest that ‘conscious awareness’ is not the only route to recruiting executive control processes.
Harlé et al. ‘Effect of affective states’	(2013)	Review	Harlé et al. (2013) expounded on the concept of ‘inhibitory control’, as a ‘rational’ process reflecting ongoing cost/benefit trade-offs between alternate courses of action. They argued that affective states were likely to affect inhibitory activity, through biasing prior expectations, associated beliefs and the value of alternative actions in achieving relevant goals.

Hunt et al. 'Performance model of self-regulation'	(2013)	Scoping review	Hunt et al.'s (2013) model also cites 'self-regulation' as an overarching process (see Barkley, 2012). It postulates that to engage in conscious, goal-directed behaviour, requires preparation and planning: processes influenced by past experiences, problem-solving skills and beliefs about one's own capability (*attributions*). When the individual moves into the behavioural 'performance' phase, the individual engages in self-monitoring to adapt to the demands required to achieve the goal. Hunt et al. (2013) considered distortions in attributions (i.e., distorted perceptions of one's performance and understanding of what this might have been due to) to be linked to ineffective self-regulation.
Mackie et al. 'Uncertainty reduction'	(2013)	Cross-sectional study	Mackie et al. (2013) suggested that attentional functions may be utilised by cognitive control processes in order to reduce uncertainty. Cognitive control was considered to be, in part, emergent from the interactions of attentional functions as they were recruited to manage uncertainty reduction and resolve conflict – reflecting less support for more componential theories of cognitive control (where it is assumed to comprise a set of discrete functions) and greater support for a mixed componential/emergent model.
Shenhav et al. 'Expected value of control model'	(2013)	Review	Shenhav et al. (2013) proposed a model which integrated three critical factors in considering the effects of motivation and effort on cognitive control: the expected 'payoff' from utilising a control process, the amount of control that must be invested to achieve the payoff, and the costs associated with the cognitive effort needed. Therefore, the 'expected value of control' (EVC) is the cumulative reward, minus the expected cost of the exertion of control.
Saunders et al. 'Cognitive comfort'	(2015)	Review	Saunders et al. (2015) presented a model in which individuals are hypothesised to regulate the implementation of cognitive control in a 'homeostatic' manner. They suggest that goal conflict is an aversive experience; therefore, individuals are therefore driven to achieve a state of 'cognitive comfort', and variation in cognitive control is related to their affective experience of task performance.

Cooper 'Multiple parallel processes'	(2016)	Mixed methods	Cooper (2016) presented a mathematical process model of how the random generation task (where subjects are required to produce sequences of 'random' response) may draw upon multiple EF. In particular, relevant processes appeared to include cognitive loading, monitoring and set-shifting.
Lieder et al. 'Learned value of control model'	(2018)	Mixed methods	Lieder et al. (2018) suggested that reinforcement learning was key to how individuals develop their understanding and adapt their use of cognitive control strategies to novel situations. Specifically, when to more intensively engage controlled processing, and suppress automatic processing, in performing Stroop and Flanker-based tasks.
Cogliati Dezza et al. 'Exploratory vs. exploitative approaches'	(2019)	Cross-sectional study	Cogliati Dezza et al. (2019) investigated the relationship between cognitive control strategies and the exploit/exploration dilemma (i.e., opting for a familiar rewarding option vs. opting for a novel, unknown outcome which may or may not come to yield greater reward). Increased cognitive load specifically hindered individuals' ability to engage in a focused 'exploratory' stance (an explicitly goal-directed strategy), as well as (in certain scenarios) affecting their ability to also engage in 'exploitative' behaviours.

Dignath et al. ‘Integrative model’	(2019)	Cross-sectional study	Dignath et al. (2019) proposed an integrated model of cognitive control. This presented top-down control (e.g., monitoring and intervention in response conflicts; Botvinick et al., 2001) and bottom-up control (i.e., retrieval) not as two opposing strategies, but rather as complementary processes, which facilitate the adaptive application of top-down strategies by ensuring their re-activation when needed, via retrieval from episodic memory.
Ritz et al. ‘Regularised optimisation’	(2022)	Mixed methods	Ritz et al. (2022) envisaged cognitive control as ‘regularised optimisation’: highlighting inter-individual flexibility in prioritising some forms of cognitive control over others. Ritz et al. suggested that ‘failures’ of cognitive control are not necessarily reflective of its limitations, but instead reflect its capacity for flexibility, and ongoing efforts to find the optimal configuration for accomplishing the task/attaining the goal at hand.

Table 2

Methodological quality ratings (adapted from SQUIRE; Ogrinc et al., 2016)

	Theoretical rationale	**Internal validity**					**External validity**		
	Rationale provided?	Methodology described in sufficient detail to be reproduced?	Operational definitions of measures?	Reliability of measures?	Construct validity of measures?	Confounding variables controlled for?	Context described?	Representative sample?	Ecological validity of measures?
Botvinick et al. (2001)	✓	✓	✓	✓	✓	✓	x	x	x
Braver et al. (2001)	✓	✓	✓	✓	✓	✓	x	x	x
Meiran & Gotler (2001)	✓	✓	✓	✓	✓	✓	✓	x	x
Gilbert & Shallice (2002)	✓	✓	✓	✓	✓	✓	x	x	x

Lavie et al. (2004)	✓	✓	✓	✓	✓	✓	x	x	x
Braver et al. (2005)	✓	✓	✓	✓	✓	✓	x	✓	x
Hester & Garavan (2005)	✓	✓	✓	✓	✓	✓	x	x	x
Altman & Gray (2008)	✓	x	✓	✓	✓	x	x	x	x
Han & Kim (2009)	✓	✓	✓	✓	✓	✓	x	x	x
Marien et al. (2012)	✓	✓	✓	✓	✓	✓	✓	x	✓
Mackie et al. (2014)	✓	✓	✓	✓	✓	✓	x	x	x
Cogliati Dezza et al. (2019)	✓	✓	✓	✓	✓	✓	x	x	x

Dignath et al. (2019)	✓	✓	✓	✓	✓	✓	x	x	x

A tick (✓) indicates that the study met the specified criterion. A cross (x) indicates that the study either did not meet the criterion, or did not provide the information necessary to establish if the criterion had been met.

Methodological quality

All studies featured a strong theoretical rationale. However, the majority tended to lack contextual/environmental information, and drew from laboratory tasks (e.g., variations on the *AX*-CT task: Braver et al., 2005; the Flanker task: Lieder et al., 2018; Stroop-based tasks: Gilbert & Shallice, 2002; Lavie et al., 2004). While confounding variables tend to be better controlled for in these studies, which are designed to elicit as 'pure' a representation of a cognitive mechanism as possible (and have received support for their validity in measuring cognitive control processes; e.g., Robinson & Steyvers, 2022), the generalisability of these results to noisy, real-world settings is limited (Spooner & Pachana, 2006). Furthermore, unrepresentative sampling was a problem across studies. As is common in psychological research, 'university students' provided the majority of participants (e.g., Lavie et al., 2004; Braver et al., 2005; Han & Kim, 2009); but given the high correlation between measures of working memory capacity (WMC) and fluid intelligence, drawing samples from selective university populations are unlikely to reflect either the true average, or standard deviation of WMC in the general population (Engle & Kane, 2004). Other studies (e.g., Altman & Gray, 2008; Gilbert & Shallice, 2002) made use of computer simulation (i.e., pseudo-random sampling using known probability distributions; Morris et al., 2019). Although increasingly popular in the neuroscientific domain (Fan & Markram, 2019), and able to provide helpful insights into computational processes, simulation studies have often suffered from a lack of clear methodological description, or adequate reporting and controlling of potential bias (Carter et al., 2019).

Narrative review

In the 29 variations of models discussed (see Table 1), there was considerable overlap, but also some differences in the terminology used in discussing EF. Multiple ‘analogous’ terms, however, are likely to be a contributing factor in the aforementioned lack of clarity regarding the theoretical underpinnings of EF. Therefore, models were reviewed according firstly to similarities and differences in terminology. This was followed by a discussion of the attentional processes referred to, and consideration of their interaction with affective/motivational states. The effort/ability of the models to provide an adaptational or ecological account of EF (i.e., applicability to real-world contexts) was also considered.

Terminology

The overlap between different disciplines in the study of EF (e.g., psychology, neuroscience, computer science) reinforces the need for consistency, and familiarity with terminology around the processes involved across these fields. For example, in neuroscience, ‘cognitive control’ research refers to efforts to understand ‘higher order’ processes as they occur in the brain, whereas ‘control theory’ in systems engineering research refers to relationships between systems and desired output states (Medaglia, 2019).

It appeared, from the selected pool of texts, that more researchers were more comfortable with using the term ‘cognitive control’ than ‘executive functions’ (with 19/28 models thus referring to goal-oriented cognitive processes: Altman & Gray, 2008; Botvinick et al., 2001; Braver et al., 2001; 2005; Cogliati Dezza et al., 2019; Dignath et al., 2019; Gable & Harmon-Jones, 2010; Gray & Braver, 2002; Han & Kim, 2009; Harlé et al., 2013; Hockey, 2011; Lavie et al., 2004; Lieder et al., 2018; Mackie et al., 2013; Meiran & Gotler, 2001; Mozer et al., 2007; Ritz et al., 2022; Saunders et al., 2015; Shenhav et al., 2013). While this may be assumed to reflect the ongoing difficulty with operationalising EF (using an alternative term perhaps enabling researchers to put, for now, the theoretical problems associated with EF to one side and concentrate on 'manageable issues'; Baddeley, 2002), substitution of the term 'cognitive control' does not resolve this issue. Like EF, the vast umbrella concept of 'cognitive control' also requires further fractionation. Five texts referred directly to EF (Barkley, 2012; Cooper, 2016; Hunt et al., 2013; Kopp, 2012; Marien, 2012). Gilbert and Shallice (2002), Engle and Kane (2004) and Kruglanski et al. (2011) referred to 'executive control' processes (which may provide sufficient means of acknowledging a connection to 'EF', and their assumed purpose). The remaining two texts used 'attentional control' (Baddeley, 2002; Hester & Garavan, 2005).

Terms more specific to the executive process under investigation (e.g., as in 'attentional control') were thought helpful, in offering an indication of how the process may relate to EF as a 'whole'. The often reductive nature of paradigms for investigating forms of attentional control (e.g., Stroop-based tasks, as used by Gilbert & Shallice, 2002; Cooper, 2016) are not necessarily well-suited to test complex hypotheses of the interactions between emotion, volition and what may constitute 'successful' adaptation (see below); however, can shed light on how 'lower level' processes may be influenced at 'higher levels' of processing. To some degree, understanding of EF is bound by this 'inverse problem': drawing from observation of lower level behavioural or neurological patterns to infer optimal control configurations to achieve goals (Ritz et al., 2022). Greater precision in terminology is likely to facilitate consistency, and improved integration of research in this multidisciplinary field.

Attentional control

The ability to select, maintain, and resist distraction from objects of attention is crucial for successfully implementing goal-directed behaviour. The influence of older models, particularly Baddeley and Hitch's (1974) working memory (WM) model, with its concept of a 'central executive', was often in evidence in the more recent models, both explicitly (e.g., in suggesting an additional component, or clarifying existing components; Baddeley, 2002; Hester & Garavan, 2005) or more implicitly (e.g., emphasis given to the interaction between attentional and memorial systems; Engle & Kane, 2004).

The premise of WM (Baddeley, 2002; Baddeley & Hitch, 1974) was that of an interface between short-term and long-term memory (STM and LTM), for the temporary storage and manipulation of information. It included modality-specific processing slave systems (the phonological loop and visuo-spatial sketchpad), which were moderated by the 'central executive'. The central executive was responsible for allocation of cognitive resources (also termed 'cognitive load'; Lavie et al., 2004) for dual task control, task switching, and selective attention. One of the main drawbacks of the original model was that of the 'homunculus' problem posed by the central executive supposedly exerting top-down influence on attentional processes (without a coherent explanation of what may direct this line of influence in favour of outstanding goals). Baddeley (2002) therefore proposed the 'episodic buffer' as an additional component of WM, to potentially resolve this problem. The 'episodic buffer' was suggested to comprise a temporary store for multisensory information, wherein information converges and is then distributed (i.e., to the central executive, and LTM). However, this 'global workspace' also does not appear too dissimilar to a 'homunculus' or notions of a 'Cartesian theatre' (Dennett, 1991). Lavie et al. (2004), in their exploration of the effects of perceptual and cognitive load on 'cognitive control', also did not elaborate on how the supervisory process might itself be organised.

However, Dignath et al.'s (2019) integrated model went some way in reconciling the 'homunculus' problem, by conceptualising both top-down and bottom-up control as mutually dependent, complementary processes. Specifically, bottom-up retrieval processes were argued to facilitate the selection of appropriate top-down strategies for specific scenarios, allowing for their flexible and adaptive application. Ritz et al. (2022), went further, highlighting the inherent purpose of adaptation as a search for the ‘optimal configuration’ of different attentional control processes to achieve desired goals. The idea of attentional control processes operating in tandem (e.g., Altman and Gray, 2008; Cooper, 2016; Han & Kim, 2009; Saunders et al., 2015) is supported by factorial analyses, suggesting that EF may consist of distinct but related processes (Miyake et al., 2000), which co-vary to produce an optimal outcome.

Braver et al. (2001; 2005), and Meiran and Gotler’s (2001) studies on the effects of healthy aging shed more light on how the application of EF can vary. Particularly, how EF may recompense for loss of control in one domain, by strengthening another. Braver et al. (2005) found that older adults tended to rely more on ‘reactive’ than ‘proactive’ control. Their hypothesis was that this may be due to a reduction in older people’s ability to prospectively maintain an optimum state of configuration of WM. However, there appeared to be an attempt to compensate for this, in the form of reactively retrieving contextual/goal-related information following presentation of the stimulus. Meiran and Gotler’s (2001) findings may also be interpreted according to Braver et al.’s (2001; 2005) ‘contextual representations’ theory. Meiran and Gotler (2001) used a task-switching paradigm, requiring participants to selectively respond to a position discrimination task. An increased reaction time for the mixed trials was found amongst older adults, even when the preparatory interval between trials was increased; suggesting that the older adults may have required extra time to retrieve relevant contextual representation and configurate WM accordingly. Braver et al.’s (2001; 2005) hypotheses offer a theoretically compelling explanation of the effects of aging on EF (and specifically WM), which goes further than the notion of a ‘general slowing’ suggested by Meiran and Gotler (2001).

A further important, but often unaddressed, theme in models of attentional control is the link between WM and consciousness. Baddeley's (2002) conceptualisation of the episodic buffer hypothesised that it retrieved information from LTM via 'conscious awareness' (p. 12). However, this 'common sense' link between executive control processes and consciousness may be an artefact from older models of EF (e.g., Shiffrin & Schneider's (1977) distinction between 'controlled' and 'automatic' processing), and/or classic experimental designs which reduce/weaken unconscious effects (Persuh et al., 2018). Marien et al. (2012) suggested that unconscious goal-related information could impair performance on unrelated tasks: arguing, on the basis of a series of trials, that the unconscious goals effectively 'hijacked' participants' available cognitive load for their own ends, leaving less resource available to complete the conscious tasks. Priming effects on the saliency of stored information in WM, and on ability to respond to cues in the environment (i.e., that when information maintained in WM is re-encountered, it is more difficult to exert executive control over it) was also discussed by Hester and Garavan (2005). Hester and Garavan (2005) considered these results in the context of addictive behaviour, but it may also have further application to other instances of hypothesised 'failure' of EF (e.g., in obsessional thinking, Okasha et al., 2000; and pathological gambling; Ledgerwood et al., 2012).

Key attentional processes, for the manipulation and processing of information relevant to task goals, included: maintenance (i.e., holding an item in WM; e.g., Engle & Kane, 2004), task-switching (e.g., Hester & Garavan, 2005), selective attention (i.e., the ability to focus attention and suppress processing of distracting/interfering information; e.g., Altman & Gray, 2008; Lavie et al., 2004), and dual task control (e.g., Baddeley, 2002). Although Harlé et al. (2013) widened discussion around 'inhibitory control', through linking it with affective and motivational states, a clear conceptualisation of 'inhibition' remains problematic and unresolved (MacLeod et al., 2003). The current review found no evidence for the necessity of inclusion of ‘inhibition’, as a distinct attentional process from the suppression of interference in selective attention.

The role of affective and motivational states

Affect and motivation fundamentally influence goal-directed behaviour. Alongside the ‘cold’ attentional processes described above, these represent the so-called ‘hot’ component of EF (Salehinejad et al., 2021).

Botvinick et al.’s (2001) ‘conflict monitoring theory’ (CMT), similarly to Baddeley and Hitch’s WM model (1974), also provided considerable influence on later models of EF (e.g., Gray & Braver, 2002; Dignath et al., 2019; Mackie et al., 2013; Saunders et al., 2015). The main premise of CMT was that cognitive control processes (i.e., EF) are deployed to regulate conflict as it occurs in concurrent processes (which is more or less inevitable given the interconnectivity, and interdependency, of neural networks; i.e., it is the ‘ubiquitous pitfall of parallel processes’, p. 625, Botvinick et al., 2001). Saunders et al. (2015) delved more into the ‘aversive’ aspect of experiencing conflict between competing goals, suggesting that individuals are inherently driven to avoid negative affective states associated with conflict, to regain a state of greater comfort: which initiates executive control. However, subjectivity in the value (and thus salience; Saunders et al., 2015) of goals, both within and between individuals, has naturally been challenging to recreate in controlled studies. Barkley (2012) also discussed this complexity, and highlighted the individual’s ‘level of dissatisfaction at failure in obtaining the goal’ as another potential variable influencing affect and motivation. It is thus difficult to reconcile laboratory tasks with real-life complications involved in managing competing goal demands. However, Marien et al. (2012) provided a creative example of an attempt to use more subjectively relevant stimuli to test their hypotheses (i.e., by using participants' own reported personal goals as primers for a memory-probe task).

Gray and Braver (2002) also added to CMT (Bodvinick et al., 2001), by discussing opposing motivational states (approach vs. withdrawal) and how these may differentially regulate goals maintained in WM. Gable and Harmon-Jones (2010) further explored the interactive effects of affect and motivation on attentional processes. Of note, they found that increased motivational intensity (either approach or withdrawal states) resulted in a 'narrowing' of attentional focus. Gable and Harmon-Jones (2010) suggested that in the event of a life-threatening situation, narrowed attentional focus may provide an adaptive measure, to help the individual to focus solely on their desired goal (e.g., escape) and reduce processing of irrelevant, peripheral information. However, this also leaves room for the idea that narrowed attentional focus today, in a markedly different environment to that of our ancestors, may at times be less adaptive and can contribute to greater anxiety (e.g., Najmi et al., 2012). Cogliati Dezza et al. (2019) reported similar findings, in the opposite direction: observing that increasing cognitive load hindered individuals' ability to engage in a 'focused exploration' task (i.e., a condition comprising a novel situation, which may or may not have come to yield greater reward than the alternative condition). The broadening of attentional focus, meanwhile, has been linked to increased mindfulness: particularly in terms of broadening attentional scope to include previously unattended, novel information (Garland et al., 2015). Taken together, these findings appear to highlight the flexibility of EF as a construct – rendering it both susceptible to affective and motivational states, as well as a moderator of affective and motivational states.

A preliminary unified model of executive functioning

A new model of EF is proposed which draws from, and attempts to unify, elements of the recent cognitive models reviewed (see Figure 2). Efforts were made to keep the model as parsimonious as possible (Packwood et al., 2011) while simultaneously attempting to account for some of the aforementioned complexities.

'Hot' and 'cold' EF have been popularly distinguished in the neurological literature (reflecting the recruitment of different areas of the PFC; Salehinejad et al., 2021), and this can be a useful premise on which to organise data (as reflected by the subheadings of the literature review above). However, as reflected in the review, there is a strong theoretical basis for continuous, reciprocal interaction between attentional control processes and affective and motivational processes, that may be unintentionally overlooked by referring to these components of EF in such categorical terms.

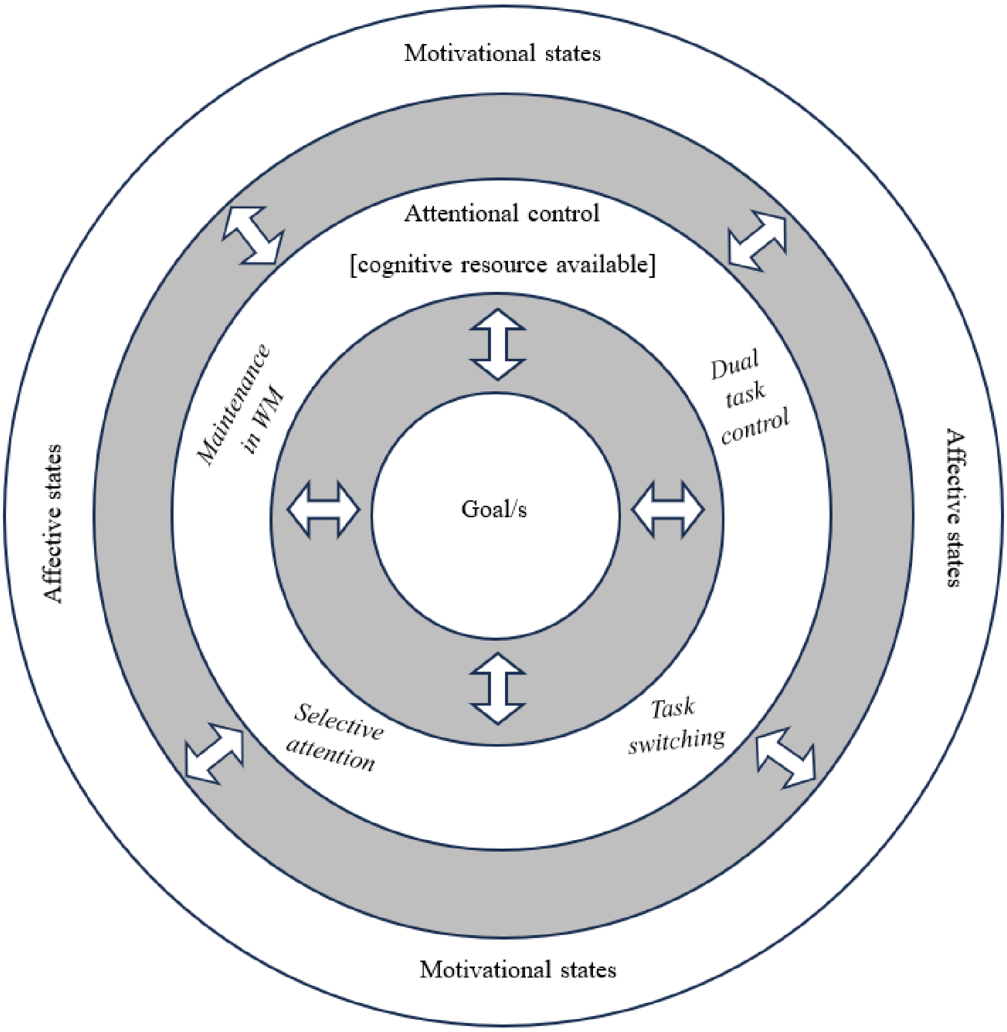
Attention is a continuous entity (always 'present' in a living person, with the exception of those in a coma). Via attentional processes of maintenance (in WM), selective attention, task-switching, and dual task control, goal-oriented behaviour can be selected, performed, evaluated and adjusted according to feedback. These various attentional processes, though separable, are strongly correlated (Miyake et al., 2000) and thus posited to work in tandem through processes of covariation (Altman & Gray, 2008). For example, tasks requiring a broader attentional scope are likely to require increased resource for maintaining larger amounts of peripheral information in WM, while selectivity can be moderated. There is limited cognitive resource available for attentional processes, which emphasises the need for a configuration of 'best fit', based on desired goals (Ritz et al., 2022), available cognitive resource (taking into account fatigue; e.g., Hockey, 2011), affective state and motivational intensity (Gable & Harmon-Jones, 2010). It is possible that in some cases of brain injury/disease/other impairment, attentional processes can become dysfunctional, or WM capacity becomes depleted, and thus covariation may occur as a means of providing compensatory measures of executive control (e.g., as may be demonstrated in older adult participants relying more on ‘reactive’ than ‘proactive’ control processes; Braver et al., 2005).

Affective and motivational states are highly important in the initiation of goal-directed attentional (and behavioural) processes. Arguably, ‘motivation’ is also not an entity which can be entirely ‘absent’ in a living person, although there is evidence that it can be severely diminished (Marin & Wilkosz, 2005). However, affect and motivation are also beholden to attentional processes, in terms of the maintenance of affective states (e.g., the influence of narrowed attentional scope on anxiety; Najmi et al., 2012) and motivational influences (e.g., cue-related drug craving; Hester & Garavan, 2005). It is therefore argued, on the basis of this unified model, that classical presentations of ‘dysexecutive syndrome’ (see Halligan et al., 2004) might represent the bi-directional failure to configure affective and motivational influences with adaptive, goal-directed behaviour.

A visual representation of the unified model (Figure 2) draws attention to the symbiotic relationship between motivational/affective states and attentional control. Drawing on available cognitive resource, the use of attentional processes to achieve a ‘best fit’ to the task at hand is also illustrated via bi-directional arrows, indicating the potential flexibility of their application.

Figure 2

Diagram of a preliminary unified model of EF



Discussion

Summary

The objectives of this review were to identify and critically examine recent cognitive models of EF, with the aim of synthesising findings to develop a unified model of EF that is based on a cohesive theoretical framework. In total, 29 texts were included in the review. These encompassed a range of published academic work including reviews, book chapters, mixed-methods and original studies, presenting varied conceptualisations of EF-related processes. The resulting unified model drew from this work to emphasise the continuous, interactional dynamics between affect, motivational states and attentional control.

Strengths and limitations

The intent underlying the search strategy was to take a broad-brush approach in its initial stages, to increase sensitivity and avoid the premature exclusion of relevant texts. However, it is of note that out of 2169 records in the initial screening phase, only 29 were deemed eligible for inclusion. This may be a consequence of the exponential increase in the use of neuroscientific data (i.e., fMRI) and computational modelling over the past 20 years (Altimus et al., 2020; Bandettini, 2012), which may possibly have been to the detriment of research interest in cognitive neuropsychology. On the other hand, it was perhaps more likely that the eligibility criteria were too restrictive, and that the review may have benefitted from efforts to expand the use of vocabulary relating to EF in the searches (e.g., by including more colloquial terms such as ‘willpower’, and ‘self-control’; Inzlicht et al., 2014). Another ramification of the resultingly small pool of texts was the lack of diversity in the participants across original studies. This was compounded by an emphasis on the use of laboratory measures, which further limited the generalisability of findings.

A strength of the current review was in its consideration of the real-life application of reviewed cognitive models, in terms of understanding difficulties encountered which might represent maladaptive configurations of EF (e.g., in obsessional thinking, Okasha et al., 2000), as well as processes which might help to optimise performance (e.g., the effect of mindfulness practices on widening attentional scope; Garland et al., 2015).

Research and clinical implications

There are many obstacles to the investigation and research of EF. Most of these are inherent within the construct itself. Given that EF is in constant implementation across a range of behaviours, it is unobservable as a 'pure' construct; thus, discernment of EF requires the measurement of performance across multiple task contexts, and calculation of the shared variance across conditions (e.g., latent variable analysis; Miyake et al., 2000; Ambrosini et al., 2019). Assessment of the validity of the unified model of EF would require such a (prospective) study design, with a more diverse range of participants. It was promising to observe in retrospect, however, that the hypotheses of the unified model appeared consistent with a recent review of neural substrates of EF (Friedman & Miyake, 2017), reflecting a simultaneously componential and emergent conceptualisation of executive function. Further research is needed in both the cognitive neuropsychological and neuroscientific domains, to specifically consider the utility of the unified model in predicting neural, cognitive and behavioural outcomes.

Although it was beyond the scope of this review to also consider developmental models, the author wished to highlight their importance in providing an interpretive context in understanding presenting difficulties; this should not be understated. For example, EF might benefit from a shift towards a more developmentally defined role, with evidence that it becomes increasingly multi-dimensional as adolescents transition into adulthood (Karr et al., 2018).

'Inhibitory' processing was omitted from the unified model, owing to the lack of evidence that it constituted a separable attentional process to *suppression* of interference/distracting information in selective attention (MacLeod et al., 2013). However, another reason for the removal of the term ‘inhibition’ centred more around semantics. Problems with ‘disinhibition’ (or ‘disinhibited behaviour’) is frequently cited as a ‘symptom’ of cognitive impairment or dysexecutive syndrome (e.g., Bonelli & Cummings, 2007); but without, it feels, due care for the subjective power of the word (also often used interchangeably with ‘impulsivity’ or ‘weak impulse control’; Joyner et al., 2021). Diagnostic labels can be powerful tools in influencing clients’ rehabilitation and recovery (Douglas, 2020) – an important part of which is their perception by others (Garand et al., 2019), as well as their own self-appraisals (i.e., attributions; Hunt et al., 2013).

Recommendations

The use of the word ‘suppression’ (or *desuppression*, in the event of distortions in an individual’s ability to selectively attend to and regulate their behaviour) is advocated as a substitute for ‘inhibition’ in research and clinical practice. ‘Suppression’ was deemed to have a stronger evidence base than ‘inhibition’ (*disinhibition*), increased neutrality, and less likely to be attached to, or attract stigmatising responses from the self or others.

Additionally, within the clinical domain, it remains vitally important that assessments of EF develop greater ecological validity (i.e., becoming more reflective of real-world issues). One example of this might be the computerised ‘FISHERMAN’ game (Wang et al., 2022), which succeeded in being well-liked by its older adult players, and was based on three hypothesised components of EF (‘inhibition’, ‘shifting’ and ‘working memory’). These attentional processes were addressed via three different subgames, wherein participants were required to ‘fish’ in changeable conditions. Spooner and Pachana (2006) also highlighted the urgent need for research methodology to bear greater emphasis on verisimilitude, for increased generalisability of findings.

In terms of recommendations for future research into EF, an interesting avenue appears to be the discipline of sensorimotor learning processing theory (Koziol et al., 2011). As suggested by Ritz (2022), the field of motor control may hold important insights for understanding the the implementation of cognitive control. This takes into consideration that voluntary and intentional acts often involve the initiation of physical movement (Bennett & Hacker, 2003). It may also offer the potential of expansion into a more 'complete' theory of 'embodied' cognition, characterised by the flexible alternation of automatic behaviour and 'higher' cognitive control.

Conclusion

This review was driven by the recognition of a developing chasm between a coherent theory of EF, neuroimaging research and clinical practice (Barkley, 2012; Bennett & Hacker, 2003). The lack of consensus on exactly 'what' EF entails in the theoretical domain (Packwood et al., 2011; Rabbitt, 1997) has also limited possibilities for valid and reliable clinical assessment, contributing to problems with the ecological and predictive validity of existing measures (Barkley & Murphy, 2010; Chan et al., 2008; Parsons et al., 2017). An argument for the importance of cognitive models, in providing a theoretical foundation for complex neuropsychological constructs (Barkley, 2012), formed the basis for reviewing recent cognitive models of EF. The 29 reviewed models were diverse in their focus, with some offering hypotheses on the link between EF and (un)conscious awareness (e.g., Hester & Garavan, 2005; Marien et al., 2012), others being primarily concerned with processes of attentional control (e.g., Lavie et al., 2004), and some emphasising the role of motivational states (e.g., Bodvinick et al., 2001; Gray & Braver, 2002). A narrative synthesis of these findings led to the development of a preliminary 'unified model' of EF. The unified model aimed to bring together the affective, motivational and attentional processes involved in goal-driven behaviour and make evident the symbiotic relationship between ‘hot’ and ‘cold’ cognitive processes. Given the limited cognitive resource available for attentional processes, there is a need for a configuration of ‘best fit’, based on desired goals (Ritz et al., 2022) and available cognitive resource (e.g., taking into account factors such as fatigue; Hockey, 2011). While the unified model remains far from being a fully explanatory account, it was hoped to provide a helpful starting point in the ongoing effort to better understand EF.

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Section B:

Deconstructing executive function: An investigation into the language and measures used to capture this elusive construct.

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Contents

Abstract

Executive function (EF) underlies the interplay of motivational, affective, and cognitive processes, and thus considered fundamental to our sense of what it means to be 'human'. Understandably, EF has proven an elusive construct to define and measure. While researchers have made some progress over the years, there are concerns regarding a gap between the construct definitions continuing to be circulated via neuropsychological assessment tools and textbooks, and the growing evidence base. To investigate this, the current study applied a content analysis to systematically examine and evaluate the ways that EF was described, and understood, in currently available assessments and textbooks. Seventeen textbooks and 12 assessments were included. Categories were deductively derived from the current evidence base, and inductively from the texts. Quantitative and qualitative analyses were carried out. Results suggested that the majority of assessments and textbooks were unlikely to provide a fully integrated account, however, there were exceptions. New leads for theoretical development, and clinical implications were discussed. Intra-individual variability was suggested as a more sensitive measure in capturing EF-related deficits than discrete assessment scores. The subjective experience and understanding of time, and its association with memory and motivation, was also identified as an area of EF in need of further investigation.

Keywords: executive function, goal-driven behaviour, qualitative analysis, theoretical development, neural integration

Introduction

Executive function (EF) is considered to be instrumental in facilitating purposeful, goal-driven behaviour. The ability to initiate and direct activity according to one's own will is inevitably a complex, multi-layered neuropsychological undertaking, which is, as yet, far from being understood (Barkley, 2012). This has not, however, prevented the introduction and widespread use of neuropsychological assessments purporting to measure EF (Chan et al., 2008), nor the dissemination of various 'definitions' of EF through textbooks, to future generations of neuropsychologists. The risk of EF becoming defined through convention, rather than according to the evidence base, is a concern which has serious theoretical and clinical implications. There is a need to establish how far existing measures and textbooks correspond to current evidence on the 'nature' of EF, its construction and application. This task requires going beyond correlation matrices: to qualitatively evaluate the language used in capturing this construct, and consider how difficulties with EF may be more helpfully understood, and communicated, by clinicians, service users and their support networks. This 'renewed' understanding of EF may then shed light on the most effective ways to support its rehabilitation.

This introduction discusses historical and current evidence that has shaped our understanding of EF, and of how it may be realised in the brain. The prefrontal cortex (PFC) is briefly introduced as the major hub by which executive activity appears to emanate in the brain. Conceptual and clinical issues with regard to delineating EF are thought about as they arise, particularly in the context of neuropsychological assessment and rehabilitation. This provides the basis for the rationale for the current study.

The prefrontal cortex

As described by Fuster (2015), the PFC is credited with the superordinate functions of representing and executing ‘new forms of organised goal-directed action’ (Fuster, 2015, p. 7). The PFC is located at the forefront of the frontal lobe of the cerebral cortex. Attempts to define the exact boundaries of the PFC have been subject to some debate. Following Brodmann’s work (1909), its definition was based on cytoarchitectonic criteria (Benton, 1991), but it is now more widely accepted as the area in heavy receipt of afferent projections from the mediodorsal nucleus of the thalamus (Fuster, 2015). This is an imperfect definition, given that connections also exist between the PFC to many other cortical and subcortical brain structures (which may be more or less ‘important’ than its thalamic connectivity). However, emphasis on understanding its relationship to other structures is considered essential to understanding the physiology and functions of the PFC (Alvarez & Emory, 2006; Fuster, 2015).

Limitations of localisation

The development of the construct of EF has been subject to both the restrictions and the advances made in the field of neuropsychology over the last two centuries. This can be summed up as an earlier reliance on single case methodology (Caramazza & Coltheart, 2006; Caramazza & McCloskey, 1988) and functional localisation, which eventually gave way to non-invasive brain imaging (Ruff, 2003), all against a rapidly changing political, social and scientific backdrop (Kuhn, 1962/2012).

In his seminal textbook, Luria (1973) offered the first description of a frontal ‘functional system’ (p. 27) that was responsible for the selection, planning, execution and monitoring of progress towards goals (Derouesné, 2018). Damage to the PFC, Luria hypothesised, was likely to result in a disconnect between the information received by the

PFC via afferent impulses, and efferent projections in response (Luria, 1973), suggesting that this would manifest in an apparent dissociation between verbal and motor responses. This was observed in tasks where patients would be able to verbally repeat simple instructions, but their performance would be subject to errors, such as perseveration (uncontrolled repetition of a prior response) and an apparent inability to follow sequences of movements (Luria et al., 1964).

However, Luria et al.'s (1964; 1973) assumptions regarding the consequences of frontal injury have been variously challenged. Some of these criticisms can be applied more generally to inferring localisation from case studies. Case studies of conditions of such rarity (e.g., Phineas Gage's injury; Harlow, 1869), while of theoretical interest, can reinforce oversimplified notions of different areas of cognition arising from discrete brain regions (Thiebaut de Schotten et al., 2015). For example, Canavan et al. (1985) reported on a case study who appeared to exhibit Luria's 'frontal lobe syndrome', but in the context of a 'global cerebral dysfunction' (p. 1052), such as may be caused by oedema, displacement or distortion, rather than a single frontal lesion. Indeed, a meta-analysis found evidence was inconsistent for the exclusive role of the frontal lobes in EF and highlighted the necessity of non-frontal areas to successful EF (Alvarez & Emory, 2006). Extra care is now demanded, in differentiating cerebral localisation from pseudoscientific, phrenological ideas (Greenblatt, 1995; Simpson, 2005; Uttal, 2003).

While historically, neuropsychological assessment has been inextricably linked with functional localisation (Ruff, 2003), the modern availability of advanced neuroimaging techniques has shifted the focus of assessments to 'function', over 'localisation' (Burgess & Alderman, 2013; Friston, 1997). It may be questioned, therefore, how traditional, performance-based measures of EF can continue to contribute usefully to clinical work (Ruff, 2003); particularly given that attempts to localise and fractionate EF have been largely unsuccessful (Barkley, 2012; Chan et al., 2008). It is possible that given the global connectivity of the PFC (Cole et al., 2010), attempting to fractionate EF (via localisation of specific processes) is an essentially inappropriate venture. In other words, the more effort that is made to measure EF through discrete clinical tasks, the less likely it is going to be that the assessment is actually evaluating EF (Manchester et al., 2004; Meltzer & Krishnan, 2007).

A second, related issue that arises in assessing EF is the so-called ‘task impurity problem’ (Burgess, 1997). Because EF necessarily recruits ‘lower level’ cognitive processes in the completion of tasks (e.g., visuospatial processing), it can be difficult to ascertain if poor performance in clinical assessments is reflective of a deficit at ‘higher’ or ‘lower’ levels of processing, or both (Chan et al., 2008; Miyake et al., 2000). By the somewhat hazy definition of EF as ‘co-ordinating goal-directed action’, a structured assessment protocol, with given instructions and an absence of distraction in the room, may be considered less likely to be testing EF than an individual’s ability to take direction, without too much independent thinking (Andrewes, 2015; Lezak et al., 2012). This may account for some of the discrepancies found between the outcomes of subjective rating scales (based on naturalistic behavioural observations, and thus considered to have higher ecological validity), and performance-based assessments of EF (Barkley & Murphy, 2010; Barkley, 2012; Toplak et al., 2013).

Issues with terminology

The term ‘executive programmes’ was introduced by Pribram (1973, p. 301). As well as a nod to Luria’s (1973) influential ‘functional system’ theory, this name also lifted from contemporary computing terminology, and referred to programmes specialised in context-specific sequencing and monitoring of routines (Bilder, 2012). However, reliance on computer metaphors may reflect the difficulty in translating ‘goal-directed behaviour’ onto clinical taxonomies of human behaviour (Barkley, 2012; Rabbitt, 1997). The philosophical and neuroscientific complexities of elucidating ‘action by volition’ were discussed in more detail by Bennett and Hacker (2003). For example, while voluntary acts often involve making a physical movement, they can also be a form of mental activity (e.g., engaging in mental arithmetic). A fully voluntary act is one where its agent controls its initiation, continuation and termination. There are many acts that are only partially voluntary (e.g., a sneeze cannot be deliberately initiated, but can sometimes be suppressed). Bennett and Hacker (2003) argued that carrying out a voluntary act cannot be said to be *caused* by a separate mental event (i.e., the prior forming of ‘an intention’; e.g., as conceived by Libet et al., 1983). They suggested that, without evidence of a causal relationship between inner acts and subsequent actions, ascribing antecedent ‘acts of willing’ to the brain could only be a cryptic form of Cartesian dualism (that remains ingrained in cognitive neuroscience). Instead, carrying out a voluntary act should instead be seen as a matter of ‘tenacity’: keeping to one’s desired purpose, until the action is complete (p. 226, Bennett & Hacker, 2003).

The confusion around this concept has probably contributed to an accumulation of what seems an excessive number of ‘subcomponents’ of EF, that are popularly referred to in the literature; and which risk muddying the conceptual waters further (Baggetta & Alexander, 2016). For example, one literature review found reference to over 68 ‘subcomponents’ of EF (including constructs such as intentionality, inhibition and information-processing; Packwood et al., 2011). While the researchers were able to reduce this number to 18 (purely on the basis of semantic and psychometric overlap), they pointed out that some of these hypothetical ‘subcomponents’ were simply descriptions of task demands of the laboratory tests used to measure them, which were likely to draw on the same underlying cognitive processes. For example, ‘inhibition’ and ‘planning’ describe task demands which appear ostensibly different, but can be achieved through identical behavioural means (Packwood et al., 2011; Rabbitt, 1997). A further issue with the multitude of terms is the difficulty it presents, in standardising and synthesising data across both research and clinical assessment tools (Baggetta & Alexander, 2016; Toplak et al., 2013).

As well as ensuring the language used is theoretically coherent, it is important that communications also take into account the socio-emotional aspect of defining difficulties with EF. In particular, the indirect (potentially covert) equating of these difficulties with moral deficiency, or weakness of character (e.g., a 'lack of self-control'; Moffitt, 1990). This is likely to evoke frightening and negative associations for service users and their support networks, potentially perpetuating feelings of being misunderstood by others (Douglas, 2020), or a lack of self-efficacy (Medley et al., 2010). Self-efficacy is significantly related to rehabilitation outcomes, with lower self-efficacy impacting negatively on individuals' acceptance of their condition, well-being and engagement in activities of daily living (Brands et al., 2014; Szczepańska-Gieracha & Mazurek, 2020).

Executive functioning as a unitary construct

Rather than being componential, there is compelling evidence that in a healthy brain, EF operates as a 'continuous' construct. It is utilised across a range of cognitive processes, and appears, theoretically and neurologically, likely to overlap with the construct of fluid intelligence (gF; Duncan et al., 1996; Gray et al., 2003; Salthouse & Davis, 2006; van Aken et al., 2016). Fluid intelligence encompasses the ability to flexibly control one's attention: providing the means to problem-solve when this knowledge is not (or only partially) available from memory (Cattell, 1971).

Developmental models offer preliminary support for this theory, with EF abilities appearing to follow a standardised trajectory through the lifespan, reciprocally influencing development of gF (Cox et al., 2010; Uka et al., 2019). Age-related changes in 'working memory' (WM; Baddeley et al., 1996) and 'inhibition' (i.e., ability to resist interference in completing a goal-oriented activity; Dempster, 1992; Diamond, 2002), happen alongside the gradual volumetric increases, and grey matter reduction of the PFC (the dorsolateral PFC being one of the last areas to reach full maturity within the brain; Morton, 2010). A simple task-switching paradigm (a card sorting test; Zelazo et al., 1995), has been used as a snapshot of this major shift in cognitive ability. Subjects are instructed to sort picture cards according to one dimension or another (e.g., colour or shape). However, when the instruction changes to focus on the other dimension, younger children tend to become 'stuck': continuing to perform according to the old rule, and being unable to apply the new rule (Bruce Morton, 2010; Diamond, 2002; Zelazo et al., 1995). This tendency towards 'attentional inertia' (the pull to continue attending to previously relevant information; Yerys & Munakata, 2006) typically diminishes by age five, and greatly reduces by adulthood. However, attentional inertia is always present to a degree (with slower reaction times consistently observed in task-switching trials; e.g., Meiran & Gotler, 2001).

However, a reciprocal relationship with gF has not been easily established for all processes associated with EF. Friedman et al. (2006) found, in a sample of young adults (16-18 years), that whereas 'updating' (i.e., the ability to monitor incoming information for relevance to the task at hand and then revise/replace items as needed in WM) was strongly correlated with gF, there was little evidence for an association between 'inhibition', or 'shifting', and gF. To explain these findings, Friedman et al. (2006) suggested that greater 'interdependency' between EF and gF may be more likely to exist among groups with compromised frontal functioning (e.g., among the older population; Salthouse et al., 2003). A problem with this theory relates to the age of Friedman et al.'s participants, whose EF capabilities also cannot be expected to have entirely matured (Bruce Morton, 2010; Dennis et al., 2013). Therefore, according to Friedman et al.'s reasoning, their participants might also have been expected to show increased interdependency of EF and gF (Hunter et al., 2012). It is possible that measures of gF particularly tap WM (Ecker et al., 2014), over and above 'inhibition' and 'shifting'; and that 'updating' and gF both reflect the ability to keep an internal representation 'active', in spite of distraction and interference (Engle et al., 1999).

Further evidence for a more continuous conceptualisation of EF, comes from studies using latent variable analysis to quantitatively define 'subcomponents' of EF (e.g., Engle et al., 1999; Miyake et al., 2000). Miyake et al. (2000) observed moderately high correlations between the three variables of 'set-shifting', 'updating' (i.e., maintaining and replacing information in working memory), and 'inhibition' (i.e., suppression of prepotent responses). It was suggested that while separable, these variables were likely to share a common underlying construct, and thus must also be, to an extent, mutually dependent. A helpful analogy may be that of an electrical circuit. The circuit connects these variables, with the size of the current and resistance representing task demands and available resource (i.e., task demands provide the motivational 'flow' of the current, whereas sufficient cognitive resource means that there is increased resistance). Unintended 'short circuits' may happen in the event of a lack of resistance (i.e., due to damage to the pathway, or fatigue). This idea of a 'configuration of best fit' based on motivation, available cognitive resource, attentional control and task demands, can be traced back to Section A (e.g., Hockey, 2011; Mackie et al., 2013; Ritz et al.,2022), where the unified model emphasised the interactional dynamics between affect, motivational states and attentional control.

While evidence supports the operationalisation of EF as a largely unitary construct in a healthy brain, the aforementioned case studies and clinical data suggest that in the event of injury or illness, this ‘unit’ disintegrates (Burgess, 2021). This perhaps illustrates that the extensive structural and functional connectivity of the PFC may also come at a cost: whereby EF is highly sensitive to even ‘mild’ occasions of injury, not limited to the frontal lobe, but including more distal sites with afferent projections to the PFC (McDonald et al., 2002). A ‘disintegration’ of the ability for goal-directed action can also be linked to the tendency for patients with EF-related deficits to often perform well on closely supervised, structured clinical assessments, while struggling to adapt to the demands of daily life (Sbordone, 2001). It may be that a focus instead on intra-individual variation (i.e., extent of cognitive dispersion), *across* neuropsychological assessments (Sorg et al., 2021) can provide a more helpful means of identifying difficulties, than individual performance on assessments measuring distinct ‘subcomponents’ of EF.

Rationale for the current study

A measure of EF is considered a key prognostic indicator for successful rehabilitation (Hanks et al., 1999; Park et al., 2015; Shea-Shumsky et al., 2019). Deficits in EF, as a result of brain injury or neurodegenerative illness, are associated with reduced quality of life (Liang et al., 2020; Perreira et al., 2008), an increase in depressive symptoms (Duggan et al., 2017), and increased family/carer burden (Burke et al., 2015). These add to the consequences already associated with labelling individuals with cognitive impairment, such as ethical concerns around exercising decisional capacity (Garand et al., 2009). There is an urgent need to better understand EF, and improve provision for individuals affected, ensuring a meaningful assessment process which can inform the most appropriate treatment options. *Commitment to quality of care*, and *improving lives*, are two core NHS values (Health Education England, 2017) which underlie these aims.

A gap currently exists between a comprehensive theoretical account of EF, neuroimaging research and clinical practice (Barkley, 2012). Section A took a tentative step towards resolving this issue by introducing a unified model of EF, based on a narrative review of its various cognitive formulations in the literature. This introduction (Section B) explores the structural and functional organisation of EF further but maintains the idea of a predominantly continuous construct in a healthy brain. It is probable that the starting premise of many popular assessment tools (i.e., aiming to localise injury; Ruff, 2003), and their intrinsic reliance on the successful 'fractionation' of EF (Chan et al., 2008), limits their usefulness. Furthermore, confusion in terminology used to describe EF has serious implications, not just for research and theoretical development (Bennett & Hacker, 2003), but also clinically (e.g., Medley et al., 2010). An improved understanding of EF can be usefully applied to evaluate how EF is described and represented in currently available assessments, as well as in textbooks. Most importantly, it can potentially guide recommendations for improving assessment practice and the possibilities for intervention.

Objectives

The objectives of the current study were to:

- Use content analysis as a means to systematically examine the language used to describe and conceptualise EF in currently available neuropsychological assessments and textbooks.
- Evaluate how far definitions and narratives around 'what EF entails' in these texts reflect current evidence on the nature and operation of EF.
- Use the results of the content analysis as a resource to generate new leads in efforts to bridge the gap between theory, neuroanatomy and clinical practice.

Method

Design

The current study took a constructivist epistemological position. A content analysis was used to systematically analyse the language used by authors to describe and conceptualise EF in currently available neuropsychological assessments, and recently published neuropsychology textbooks. This included both quantitative (descriptive) and qualitative (manifest and latent) analyses, holding an awareness of the subjectivity of the authors' various understandings and readers' interpretations.

Ethical considerations

This study was restricted to the analysis of texts available in the public domain, thus waiving the need to seek informed consent. It was therefore exempt from formal ethical review. However, undertaking a textual analysis demands an ongoing self-reflexivity on the part of the main researcher, to consider the principal motives behind the research, and ensure the representativeness and fidelity of the analysis to the texts under review (McKinnon, 2012).

Data sample

The data sample included manuals of assessments of EF (see Table 1) evidenced as currently available for use by practicing clinical neuropsychologists. Existing assessments were first identified from the taxonomies of assessments currently available in Lezak et al. (2012) and Strauss et al. (2006); as well as recent evidence in the literature (e.g., Casaletto & Heaton, 2017; Rabin et al., 2016). The assessments were required to be available in analogue (i.e., not exclusively in a digital format). This requirement was imposed because of the ongoing popularity of traditional pen-and-paper tests among neuropsychologists, relative to computerised tests (Schmand, 2019). Manuals of neuropsychological test batteries which included subtests of EF (e.g., Dementia Rating Scale; DRS-II, Jurica et al., 2001) were also included. Assessments needed to have been validated for use with adults (≥18 years old). There were no restrictions with regards to assessment contexts, with the exception of diagnostic assessments for neurodiverse presentations such as autism, or ADHD. Due to the complexity of the interplay between genetic, neurological and developmental factors associated with these diagnoses (Hinshaw, 2018), as well as the tendency for these assessments to focus on developmental/educational reports (Schilbach, 2022), these were considered outside the scope of the current study. However, this study included assessments designed to measure EF across a variety of presenting conditions (e.g., acquired brain injury, and neurodegenerative conditions such as dementia). Occasionally, where tests were originally developed decades prior (e.g., Stroop, 1935), the original citation was retrieved, or an updated test manual (if available) was examined, to reflect its operationalisation in modern clinical practice. The availability for use/purchase of these assessments was checked via online searches, including of the university and public libraries (e.g., the British Library).

Neuropsychology textbooks were also included in the data sample (see Table 2). These were defined as academic books offering a compilation of information specific to neuropsychology, with the intention of explaining concepts and/or providing guidance on their clinical application. To be included, textbooks were required to have been published in English within the last 10 years (2012-2022), and attempt to define or conceptualise EF. As with the assessments, the textbooks were required to refer to EF in the context of an adult brain, and not be specific to neurodiverse presentations. As discussed, a 'developmental' view of EF (or even a discussion of its evolutionary transformation, e.g., Barkley, 2012), is vital to our understanding of how individuals may come to accumulate EF-related skills. However, there is a need to complete this line of enquiry, with a conceptualisation of EF as it may exist as a ‘finished product’. Therefore, texts exclusively focusing on the neurodevelopmental trajectory of EF were excluded. Likewise, texts exclusively focusing on the history of neuropsychological understanding of EF, rather than presenting an up-to-date view/idea of EF, were also excluded. Lastly, given the potential depth and breadth of focus on the neurological substrates of EF (across texts), it was thought that this would be most usefully restricted to discussions of interconnections/networks (rather than functional descriptions of single brain regions). Information on cytoarchitecture and neurotransmission (e.g., role of dopamine) was excluded.

An inclusive approach was taken, with efforts made to include textbooks using alternative terminology/models, if these were understood to correspond to EF (e.g., social cognitive neuroscience; Schutt et al., 2015). Textbooks were discovered via the use of library search engines (using the search term ‘neuropsychology’). Results were refined based on publication date and checked for possible reference to EF via contents lists (see Figure 1).

Table 1

Assessments of EF included in analysis

Title / Authors	**Relevant subtest(s)**
The Stroop Test (Stroop, 1935; Trenerry et al., 1989)	
Wisconsin Card Sorting Test (WCST; Berg, 1948; Grant & Berg, 1948; Heaton et al., 1993)	
Self-Ordered Pointing Test (SOPT; Petrides & Milner, 1982)	
Iowa Gambling Task (Bechara et al., 1994)	

Ruff Figural Fluency Test (RFFT; Ruff et al., 1996)	
Behavioral Assessment of the Dysexecutive Syndrome (BADS; Wilson et al., 1996)	Rule Shift Cards Test
	Action Program Test
	Key Search Test
	Temporal Judgement Test
	Zoo Map Test
	Modified Six Elements Test
	The Dysexecutive Questionnaire
Hayling and Brixton Tests (Burgess & Shallice, 1997)	Hayling Sentence Completion Test
	Brixton Spatial Anticipation Test
Delis-Kaplan Executive Function System (DKEFS; Delis et al., 2001)	Word Context Test
	Sorting Test
	Twenty Questions Test
	Tower Test
	Colour-Word Interference Test
	Verbal Fluency Test
	Design Fluency Test
	Trail Making Test
	Proverb Test
Frontal Systems Behavior Scale (FrSBe; Grace & Malloy, 2001)	
Dementia Rating Scale-2 (DRS-2; Jurica et al., 2001)	Conceptualisation
	Initiation/Perseveration
Neuropsychology Assessment Battery (NAB; Stern & White, 2003)	Mazes
	Judgement
	Categories
	Word generation
Short Parallel Assessments of Neurological Status – Extended (SPANS-X; Burgess, 2021)	Attention/Concentration
	Cognitive Flexibility

Figure 1

Search strategy for textbooks

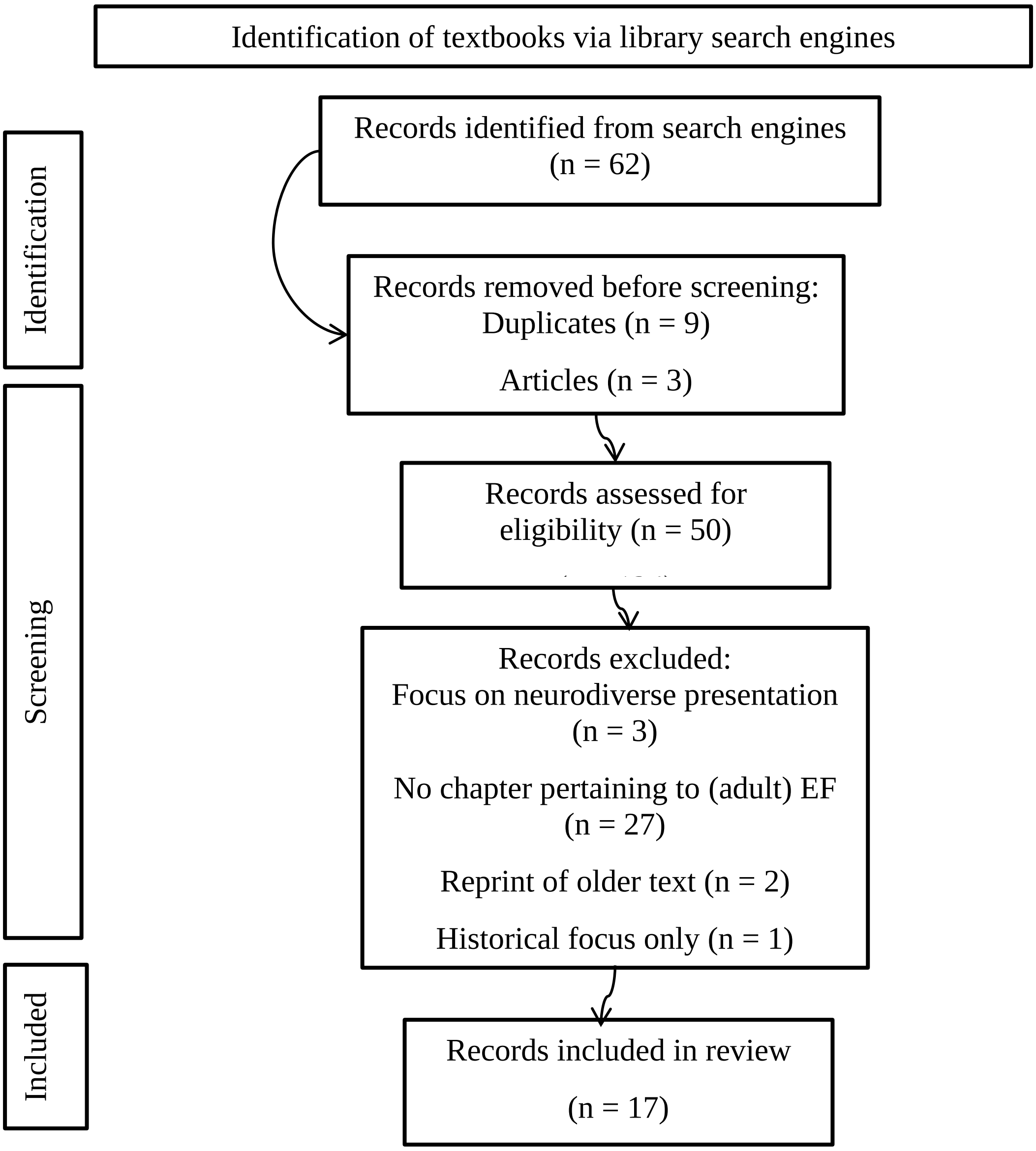


Table 2

Textbooks included in analysis

Authors / Textbook	**Textbook / relevant chapter(s)**
Executive Function and Dysfunction: Identification, Assessment, and Treatment / Hunter & Sparrow (2012)	Chapter 1: Models of executive functioning (pp. 5-16; Hunter & Sparrow, 2012); Chapter 3: The neurobiology of executive functions (pp. 37-64; Hunter et al., 2012).
Neuropsychological assessment (5th ed.) / Lezak et al. (2012)	Chapter 16: Executive functions (pp. 666-711; Lezak et al., 2012).
Clinical Neuropsychology: A Practical Guide to Assessment and Management for Clinicians (2nd ed.) / Goldstein & McNeil (2013)	Chapter 9: Executive dysfunction (pp. 209-238; Burgess & Alderman, 2013)
Neuropsychological neurology: The neurocognitive impairments of neurological disorders (2nd ed.) / Larner (2013)	Chapter 1: Cognitive function, neuropsychological evaluation and syndromes of cognitive impairment (pp. 1-16; Larner, 2013).
Practical neuropsychological rehabilitation in acquired brain injury: A guide for working clinicians / Newby et al. (2013)	Chapter 1: Behavioural neuroanatomy (pp. 13-26; Coetzer, 2013)
Feedback that sticks: The art of communicating neuropsychological assessment results / Postal & Armstrong (2013)	Part 2: Putting feedback to work: Explaining executive function and frontal impairment (pp. 77-79; Postal & Armstrong, 2013).
Clinical neuropsychology: A pocket handbook for assessment (3rd ed.) / Parsons & Hammeke (2014)	Chapter 21: Frontal lobe function (pp. 498-524; Floden, 2014)

Neuropsychology: From theory to practice (2nd ed.) / Andrewes (2015)	Chapter 4: Executive dysfunction (pp. 197-298)
Social neuroscience: Brain, mind, and society / Schutt et al. (2015)	Chapter 2: The evolution, structure and functioning of the social brain (pp. 29-40; Keshavan, 2015).
An introduction to brain and behavior (5th ed.) / Kolb et al. (2016)	Chapter 12.4: Neuroanatomy of motivated and emotional behavior: Executive function of the frontal lobes (pp. 418-420).
The neuroscience of psychotherapy: Healing the social brain / Cozolino (2017)	Chapter 7: The executive brain: Directed action and inhibition (pp. 119-139); Chapter 8: The executive brain: Navigating space and time (pp. 140-155); Chapter 9: The executive brain: Discovering others and finding the self (pp. 156-172)
Biological Psychology (13th ed.) / Kalat (2017)	Chapter 13.2: Conscious and unconscious processes (pp. 441-451); 13.3: Making decisions and social neuroscience (pp. 452-456)
Neuropsychological rehabilitation: The international handbook / Wilson et al. (2017)	Chapter 17: Rehabilitation of executive functions (adults) (pp. 209-212; Spikman, 2017).
The brain and behavior: An introduction to behavioral neuroanatomy (4th ed.) / Clark et al. (2018)	Chapter 6: Frontal lobe (pp. 73-102; Clark et al., 2018).
Cognitive neuroscience: The biology of the mind (5th ed.) / Gazzaniga et al. (2019)	Chapter 12: Cognitive control (pp. 514-565)
Social cognition: From brains to culture (4th ed.) / Fiske & Taylor (2020)	Chapter 13: From social cognition to affect (pp. 383-414); Chapter 14: From affect to social cognition (pp. 415-440); Chapter 15: Behavior and cognition (pp. 441-472).

Fundamentals of human neuropsychology (8th ed.) / Kolb & Whishaw (2021)	Chapter 16: The frontal lobes and networks (pp. 395-424)

Data analysis strategy

A content analysis was used to examine the data. The strategy closely adhered to the three-phase approach to conducting a deductive content analysis described by Assarroudi et al. (2018; see Figure 2). The deductive approach enabled a structured, systematic analysis of the concordance of the texts with the current literature on EF (Elo & Kyngäs, 2008). Thus, *a priori* categories were chosen for the categorisation matrix, based on a developed theoretical understanding of EF (as established in Section A, and further elaborated on in the introduction of Section B). However, Assarroudi et al's (2018) approach also included an inductive phase by which new categories to the categorisation matrix could be added, in the event of new material emerging from the texts. This step ensured that the analysis remained representative of the data, as well as providing the opportunity to gather, and make sense of, additional insights offered by the texts. The texts were then coded according to the categorisation matrix. Descriptive quantitative and further (manifest and latent) qualitative analyses were then completed on the coded texts. Particular attention was given to the context of meaning units, and comparison of the reviewed texts with current evidence.

Development of the categorisation matrix

The categorisation matrix provided a framework for the systematic coding of the texts (see Table 3). Two superordinate categories, 'neuroanatomy' and 'theoretical application' were chosen, as the most generalised means of sorting the data. Main categories were initially chosen based on elements of the 'unified model' of EF described in Section A (i.e., 'attentional processes', 'affective and motivational processes', and 'limited cognitive resource'). These were further divided into subcategories (e.g., 'attentional processes' was split into 'selective attention', 'task switching', 'dual task control', 'updating [working memory]', and 'overlap with gF'). Other main categories (and subdivisions) were added based on further evidence on the structure and function of EF, as explored in the introduction of Section B (e.g., 'structural and functional integration' was split into 'cortical and subcortical integration', 'specialised networks', 'continuous construct (in a healthy brain)', and 'disintegration (in the event of illness/injury)').

The 'meaning units' selected for inclusion in the content analysis were the themes which arose in association with attempts to define, or conceptualise, EF in the selected texts. 'Themes' were chosen as meaning units over single words/terms. Single words were considered likely to be less representative of the content and to risk its fragmentation (Elo & Kyngäs, 2008). This was relevant particularly considering the complexity of EF, and its representation as an integrated model: fragmenting the texts into single words may have undermined authors' efforts to convey this aspect of EF in their writing. Category rules, and 'anchor' samples were chosen to demarcate and illustrate how each category would be represented in the texts (see Table 4; Mayring, 2020). An 'anchor' sample should be a clear and concise example of a meaning unit, representing a category in the texts (Mayring, 2014). A test on a subset of the texts with the initial categorisation matrix was carried out to allow for a check of inter-rater reliability, using Krippendorff's α (Krippendorff, 2004). Any ambiguities in the coding frame were revised, until the two coders (lead researcher, KA, and external postgraduate researcher) agreed that these had been resolved. The meaning units were given preliminary codes, before being abstracted into generic categories, which were then abstracted further into the subordinate and main categories of the categorisation matrix (see Table 5 for examples). This process also allowed for the inductive emergence of new categories.

Figure 2.

Three-phase approach to content analysis (adapted from Assarroudi et al., 2018)

Phase 1

Preparation

- Acquisition of general knowledge relating to chosen research method and/or theoretical topic of interest.
- Decision regarding the selection and eligibility criteria for the texts included in the content analysis.
- Decision on whether analysis should include manifest and/or latent content.
- Specification of the meaning unit(s) for analysis.

Phase 2

Organisation

- Development of a formative categorisation matrix from existing theory/previous research.
- Provision of theoretical definitions of main categories and subcategories.
- Determination of coding rules for main categories.
- Trial testing of the categorisation matrix. Difficulties to be discussed with external coder and categories revised until all ambiguities are resolved.
- Choice of an anchor sample for each category.
- Performance of the data analysis (identifying meaning units and giving these preliminary codes).
- Inductive abstraction of main categories from preliminary codes (a grouping process initially resulting in 'generic categories'; Elo and Kyngäs, 2008).
- Establishment of links between generic categories, subcategories and main categories (inductively creating new categories where necessary).

Phase 3

Reporting

- Provision of a detailed description of the data analysis process.
- Systematic presentation of findings which demonstrate the association between the raw data and categorisation matrix.

Table 3.

Initial (deductive) categorisation matrix

Overarching categories	**Neuroanatomy**		**Theoretical application**		
Main categories	**Structural and functional integration**	**Limited cognitive resource**	**Facilitation of goal-directed behaviour**	**Attentional processes**	**Affective and motivational processes**
Subcategories	Integration of cortical and subcortical systems	Co-variation in utilisation of processes	Planning	Selective attention	Motivational intensity
			Adaptation to novel situations		
	Specialised networks	Configuration of best fit		Task switching	Reciprocal influence of affect and attentional processes
	Continuous construct (in healthy brain)			Dual task control	
	Disintegration (in the event of illness/injury)			Updating (WM)	
				Overlap with gF	

Table 4.

Category rules and anchor samples for deductive categories

Main categories	Subcategories	Category rule	Anchor sample
Structural and functional integration	Integration of cortical and subcortical systems	A 'whole brain' approach to understanding EF, based on interconnecting neural networks between the PFC, posterior areas and the brainstem.	*'Cognitive control requires the integrated function of many different parts of the brain.'* (p. 516, Gazzaniga et al., 2019)
	Specialised networks	Reference to specialised networks within the brain associated with EF-related processes (e.g., selective attention).	'*A group of special 'hyperdirect' fibers from both the pre-SMA and SMA project directly to the subthalamic nucleus of the basal ganglia. Activation of these fibers would rapidly 'brake' any ongoing activity in the cortical-basal ganglia circuit…*' (p. 78, Clark et al., 2018)
	Continuous construct (in healthy brain)	Suggestion of EF as operating as a continuous (as opposed to a categorical) construct within the healthy population.	*'It may be that most cognitive functions operate collectively, seamlessly, undetectably, unitarily – until something goes wrong in the brain.'* (p. 40, Burgess, 2021)
	Disintegration (in the event of illness/injury)	Explaining executive 'dysfunction' in terms of an interruption in circuitry (and system	*Executive functions can break down at any stage in the behavioral sequence necessary for planned or intentional activity.*' (p. 666, Lezak et al., 2012)

		breakdown). This may be temporary until alternative pathways are formed.	
Limited cognitive resource	Co-variation in utilisation of processes	Describing a system whereby multiple attentional processes are recruited simultaneously, to differing degrees.	'*Attentional resources, which are finite, are devoted to some channels but not to others.'* (p. 2, Larner, 2013)
	Configuration of best fit	Considering the need for the system to adapt to an optimal state, based on specific task demands and available resource.	*'The ongoing interaction between the organism and its environment leads to a state of dynamic equilibrium, termed homeostasis…'* (p. 33, Keshavan, 2015)
Facilitation of goal-directed behaviour	Planning	Describing the use of EF in effective planning and organisational behaviour to achieve goals.	*'…[The Key Search Test] enables us to examine the subject's ability to plan an effective and efficient course of action...'* (p. 6, Wilson et al., 1996)
	Adaptation to novel situations	Describing contribution of EF to managing/ successfully adapting to novel situations.	*'…the term executive seems an appropriate one for a system that influences other brain areas toward adaptation to novel circumstances…*' (p. 211, Andrewes, 2015)
Attentional processes	Selective attention	Drawing from Section A, this encompassed references to 'inhibition/suppression' of prepotent responses or distractor information, to reflect the ability to tenaciously keep to the task at hand (Bennett & Hacker, 2003).	'*Attention is thus effortful, selective and closely linked to intention.*' (p. 2, Larner, 2013)

	Task switching	Referring to the ability to disengage from an irrelevant task set and then actively engage a relevant task set (Miyake et al., 2000).	*'The Wisconsin Card Sorting Test (WCST) was originally developed to assess abstract reasoning ability and the ability to shift cognitive strategies…'* (p. 1, Heaton et al., 1993)
	Dual task control	Describing the ability to perform two tasks simultaneously (i.e., divided attention).	*'…an assessment of a dysexecutive patient should include…a measure of multitasking ability…'* (p. 219, Burgess & Alderman, 2013)
	Updating (WM)	Describing the ability to monitor incoming information for relevance to the task at hand and then revise/replace items held in working memory (Morris & Jones, 1990).	*'…he must constantly compare the responses that he has made to those that still remain to be carried out. In other words. the self-ordered test makes considerable demands on an active, working memory.'* (p. 260, Petrides & Milner, 1982)
	Overlap with gF	Suggestion of shared variance between EF and gF.	'*Tests of fluid intelligence that require novel problem-solving inevitably do test some aspects of executive skills in a broad and modest way…*' (p. 200, Andrewes, 2015)
Affective and motivational processes	Motivational intensity	Considering the strength and salience of motivation in the facilitation of goal-oriented behaviour (i.e., implementation of EF).	'*Motivation, including the ability to initiative activity, is one necessary precondition for volitional behaviour*.' (p. 667, Lezak et al., 2012)
	Reciprocal influence of affect	Considering the influence of affect (e.g., anxiety) on attentional processes (and vice versa).	'*Abstract thinking and problem solving are particularly dependent on adequate emotion regulation.*' (p. 127, Cozolino, 2017)

	and attentional processes		

Table 5.

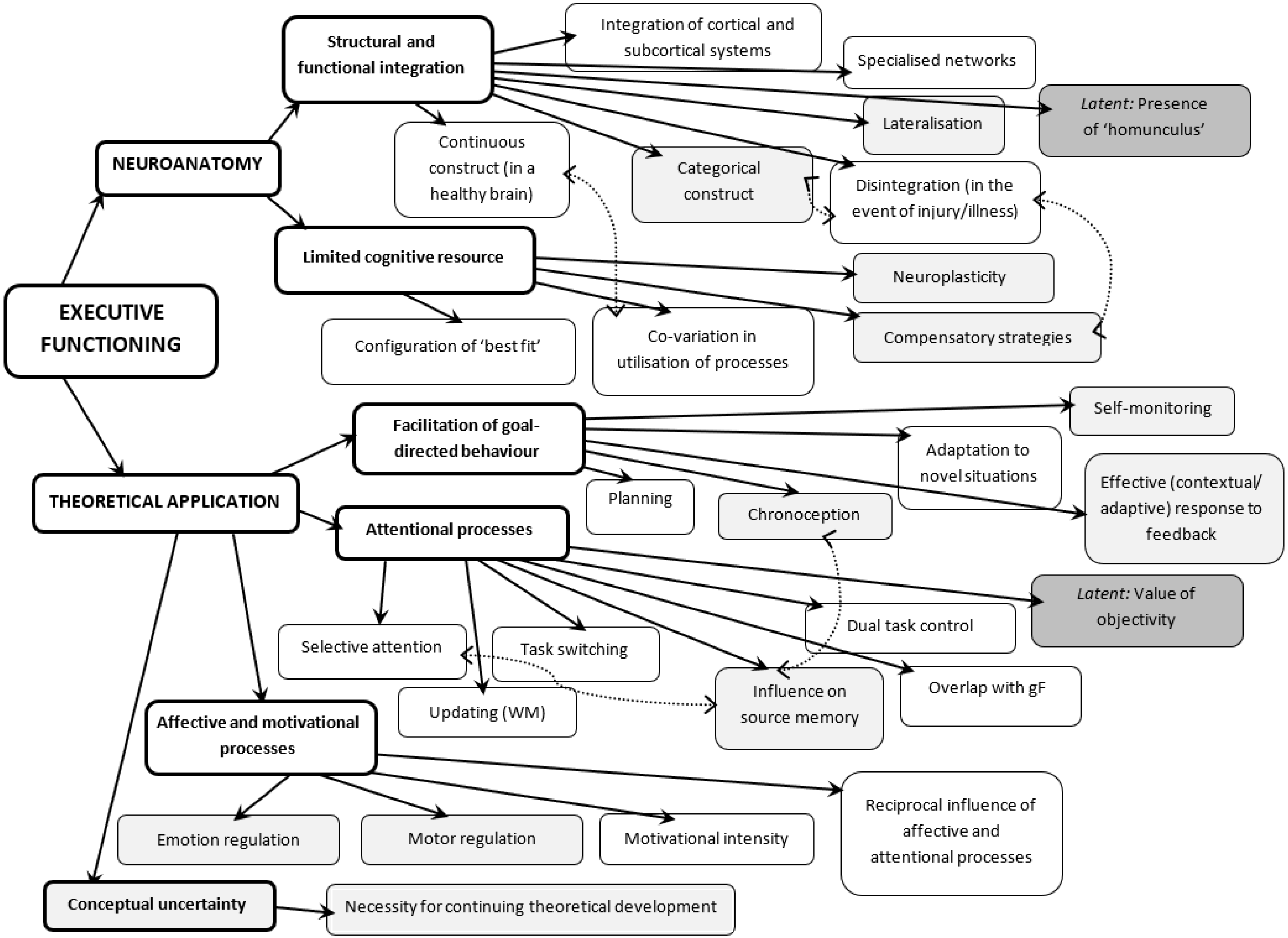
Process of abstraction of the main category

	Meaning unit	Summarised meaning unit	Preliminary code	Group of codes	Generic category	Subcategory	Main category
Deductive	*'Cognitive control requires the integrated function of many different parts of the brain.'* (p. 516, Gazzaniga et al., 2019)	Cognitive control (i.e., EF) depends on the integrated activity of multiple brain regions	Successful EF depends on functioning at multiple levels within the brain	Dependence on multiple areas and varying levels of the brain	Reliance on interconnectivity between brain structures	Integration of cortical and subcortical systems	Structural and functional integration
	'The functional specificity of the	The connectivity of the frontal lobes with	Successful EF relies on				

	frontal lobes is also reflected in connections with subcortical regions.' (p. 508. Floden, 2014)	subcortical regions provides the necessary neurological apparatus for functions such as EF	functioning at multiple levels within the brain				
Inductive	*'…[The Key Search Test] can look at the subject's ability to monitor his/her performance...'* (p. 6, Wilson et al., 1996)	EF involved in self-monitoring of one's performance	EF implicated in self-assessment of one's ability/progress towards goal(s)	Intact EF associated with (more accurate) ability to self-appraise performance	EF affects ability to self-appraise performance	Self-monitoring	Facilitation of goal-directed behaviour

Figure 3.

Conceptual map of deductive and inductive categories



Inductive categories are shaded light grey. Latent categories are darker grey. Hypothesised associations between categories are represented via bi-directional dotted arrows.

Results

Twelve assessments and 17 textbooks were included in the content analysis (see Tables 1 and 2). Five main categories and 15 subcategories were deductively derived from the current evidence base to form the initial categorisation matrix. There was strong interrater reliability for the deductive categories (Krippendorff's $\alpha = 0.85$, $p < .001$; Krippendorff, 2004), with any disagreement resolved through discussion. There was one inductively derived main category, 11 subcategories and two latent categories. The full range of categories and their hypothesised associations are depicted in a conceptual map of EF (see Figure 3; Pope et al., 2000). A table of frequency counts and textual representations for each category is supplied in Appendix I.

The content analysis process

Given that EF has previously been associated with an 'excess' of terms and hypothesised functions (Packwood et al., 2011), as well as the current study's concerns regarding clarity in communication with stakeholders (Brenner, 2003), efforts were made to ensure the final categorisation matrix was as parsimonious as possible, while not undermining the complexities in the texts (or of the construct itself). The identification of new preliminary codes required frequent reappraisals of the included texts, and comparison against the existing matrix, to refine the codes into generic, subordinate and then main categories (see Table 5).

Quantitative analysis

The most frequently referenced subcategory was selective attention (in eight assessment tools and 14 textbooks). This was followed by task switching (nine assessments and nine textbooks), effective (contextual/adaptive) response to feedback (five assessments and 10 textbooks), and integration of cortical and subcortical systems (zero assessments, 14 textbooks). The latter finding might be understood in terms of differing textual objectives (i.e., assessments being designed for practical application rather than disseminating knowledge), as well as differences in dates of publication (textbooks were required to have been published from 2012), and thus a changing evidence base. However, paradigms such as the Stroop test (Stroop, 1935) and WCST (Berg, 1948; Grant & Berg, 1948; Heaton et al., 1993), which have existed for the past 75 years, but have been redesigned and incorporated into newer tests (e.g., the 'Sorting Test', Delis et al., 2001), still appeared powerfully associated with mental processes related to EF (despite differing views on exactly which processes these tasks 'tap' into; see further qualitative analysis below). These frequency counts may be more illustrative of a past emphasis on 'explaining' EF in terms of laboratory-based measures, rather than at a more social, personal or biological level.

Qualitative analysis

Structural and functional integration

Integration of cortical and subcortical systems was described in 14 textbooks (e.g., '*…executive functions depend not only on frontal cortical areas but also on many other brain areas that are linked…through larger executive control networks*', Kolb & Whishaw, 2021, p. 404). This was considered a promising move away from the assumptions of 'localisation', to a more sophisticated view of EF, as supported by neural circuitry across brain regions. Specialised networks were referred to by 11 texts (10 textbooks). Although there was some disparity in how these were described (e.g., discussing a 'rostral-caudal axis' as opposed to an 'anterior-poster axis' for abstract vs. sensory/concrete processing; Floden, 2014, p. 505; Gazzaniga, 2019, p. 525), there was general agreement on the importance of the salience network (SN), ventral and dorsolateral PFC networks in the dynamic control of attention, and interconnections between the ventromedial PFC and the limbic system in affective and motivational processing. Lateralisation was referred to by 10 texts (seven textbooks). The left hemispheric specialisation for language (vs. right specialisation for visuospatial abilities) was highlighted (e.g., '*...patients with right frontal and right fronto-central lesions were more impaired on tasks of design fluency than those with left frontal lesions*', Ruff, 1996, p. 1). Given the role of language ('inner speech'; Vygotsky, 1962) in self-regulation and updating WM, left hemispheric lesions were considered potentially more detrimental to aspects of EF (Petrides & Milner, 1982).

The idea of EF comprising a continuous construct (in the healthy population) was suggested in only five texts (e.g., *'It may be that most cognitive functions operate collectively, seamlessly, undetectably, unitarily – until something goes wrong in the brain',* Burgess, 2021, p. 40). While acknowledging the intercorrelations between 'executive' processes in the 'intact brain', Delis et al. (2001, p. 53) suggested this was an 'illusion' of a unitary construct, undermined by the apparent dissociation of these abilities following variously located frontal lesions. However, Burgess (2021) hypothesised that it was the disruption to circuitry caused by the injury which is likely to create such a breakdown, and resulting 'constellation' of 'dysexecutive' symptoms (e.g., Wilson et al., 1996). A greater number of texts (n = 8) endorsed a more categorical approach to EF (e.g., '*...there are likely multiple executive subsystems that are anatomically and behaviourally separate'*, Kolb & Whishaw, 2021, p. 404). It was unclear, aside from evidence relating to specialised neural networks and lesion studies (which do not in themselves support the fractionation of 'intact'

EF), why texts appeared to favour a more categorical approach. Latently, some meaning units seemed reminiscent of Cartesian dualism (i.e., the necessity for a 'homunculus' within the brain, e.g., '*…the front of the brain is the conductor…'*, Postal & Armstrong, 2013, p. 77). The 'persuasive' nature of this fallacy (Dennett, 1991, p. 107) may be in its similarity to intuitive experience of consciousness (i.e., the 'self' as guiding and controlling behaviour). However, this may equally be responsible for a more sequential (and thus categorical) view of EF: that of a 'conductor', who initiates action and then watches events unfold, rather than the capacity for 'tenacity', with which one is able to sustain a motivation to see her objectives through (Bennett & Hacker, 2003).

The concept of disintegration [of EF] (in the event of illness/injury) was described in only five texts. However, among these, it was often reported as a 'disorganisation' or a 'dissociation' (i.e., a 'disconnect' between intention and behaviour; e.g., '…*knowing-doing dissociation*…', Burgess & Alderman, 2013, p. 212); appearing to echo earlier ideas from Luria's systems theory (Luria, 1973).

Limited cognitive resource

Only three textbooks referred to the operation of EF via co-variation in utilisation of processes (e.g., '*Attentional resources, which are finite, are devoted to some channels but not to others*', Larner, 2013, p. 2). Two of these textbooks (Andrewes, 2015; Cozolino, 2017) also described a configuration of best fit (n = 3) approach to task demands. Interestingly, while the remit of the third textbook in this group was in social cognitive neuroscience, it helpfully extended the concept of an inner '*homeostasis*' (Andrewes, 2015, p. 210) to the '*dynamic equilibrium'* of '*the ongoing interaction between the organism and its environment*…' (Keshavan, 2015, p. 33).

Neuroplasticity was referred to by four texts (e.g., '…*the relationship between neuromodulatory pathways and the PFC is dynamic and ultimately contributes to cognitive plasticity as well as skill acquisition*', Hunter et al., 2012, p. 57). On this basis, the extensive connectivity of EF suggests that it is particularly sensitive to experiential learning (i.e., learning associations); which makes task switching ability an essential counterbalance to habit formation (e.g., Allom et al., 2018).

The compensatory strategies (n = 7) referred to in the texts were both internally and externally driven (and therefore, considered likely to be recruited both consciously and unconsciously). Surprisingly, the impact on assessed performance was accounted for by only three assessments (e.g., '*Some subjects may attempt to improve their performance…by covering up part of the word in order to reduce the interference effect*', Trenerry et al., 1989, p. 4).

Facilitation of goal-directed behaviour

'Goal-directed behaviour' clearly encompasses a huge remit of cognitive, emotional, and behavioural processes, and therefore is perhaps more appropriate for use as a convenient 'shorthand' for introducing EF, rather than being a functional definition *per se*. The ability to engage in planning (e.g., '…*those cognitive abilities that enable a person to determine goals, formulate new and useful ways of achieving them*…', Burgess & Alderman, 2013, p. 209) was described by 13 texts. Adaptation to novel situations (e.g., *executive functions are intrinsic to the ability to respond in an adaptive manner to novel situations*…', Lezak et al., 2012, p. 666) was only referred to by five texts. However, this definition was potentially more helpful, bridging a laboratory-based measure of EF (specifically, 'task switching' ability) with its real-life application.

Involvement of EF in self-monitoring appeared in eight texts (e.g., '*[The Key Search Test] can look at the subject's ability to monitor his/her own performance...'*, Wilson et al., 1996, p. 6) and also seemed translatable to the attentional process of 'updating WM'. However, patients with EF-related deficits were more often discussed in terms of 'lacking insight' (e.g., Andrewes, 2015; Burgess & Alderman, 2013; Wilson et al., 1996) rather than difficulties in updating, and integrating, changes in awareness of self, others and context (Lezak, 2012). Effective (contextual/ adaptive) response to feedback, was referred to by 15 texts (e.g., *'[The WCST requires] the client to use the examiner's feedback…*', Heaton et al., 1993, p. 1). This involved using cues to modify one's thinking and behaviour where needed (also linked to successful task switching). This was identified as an element missing from the 'unified model' of Section A, which did not specifically account for an (external) feedback loop impacting response selection.

'Chronoception', or the subjective experience of time, was inductively identified from eight texts (e.g., '*…the coordination of a complex set of actions that may unfold over an extended period of time…*', Gazzaniga et al., 2019, p. 516). This was considered likely to be an important aspect of EF, and necessary addition to future models. The association between an abstract appreciation of 'time', memory, and motivation is inevitably complex, and yet to be explored with regards to its influence on EF. Difficulties with the chronological 'arrangement' of one's experience might be expected to cause extreme disruption: not only to the individual's planning and decision-making abilities (e.g., Bechara et al., 1994), but also to features of their narrative identity (McAdams & McClean, 2013).

Attentional processes

Selective attention was a broad category, comprising meaning units from across 22 texts. Dissimilar-looking meaning units seemed to reflect the preponderance of terms used to describe (what was assumed to be) the same cognitive process (e.g., '*the ability to sustain concentration*', Burgess, 2021, p. 110, and *'the ability to suppress a prepotent response*, Floden, 2014, p. 512, were both categorised as 'selective attention'). It is of note that Stroop (1935) himself observed that the terms interference and inhibition 'seem to have been used almost indiscriminately' (p. 643, Stroop, 1935). Beyond the laboratory, Cozolino (2017) considered the role of 'selective attention' in Eastern meditative practices as encouraging a focus on the 'inner' world ('*…it requires that we are able to sustain focus on our bodies and in our imaginations'*, p. 156), highlighting the ability to 'disengage' attention from external stimuli as essential to self-regulation, and psychological wellbeing.

Task switching was referred to by 18 texts. Multiple terms were also used (e.g., '*the ability to abstract'*, Jurica et al., 2001, p. 8; '*mental flexibility'*, Stern & White, 2003, p. 10; '*reasoning*', Kolb & Whishaw, 2021, p. 403; '*to conceive of alternatives',* Lezak et al., 2012, p. 671). Again, their semantic similarity suggested that these referred to the same cognitive process, though at differing levels of abstraction. 'Task switching' offered a concrete (behavioural) description of laboratory task demands. 'Abstract reasoning', the ability to disengage from immediate physical experience and 'switch' focus to one's internal repertoire of information, offered a functional description of the subjective experience of problem-solving. Degree of mental (or cognitive) flexibility was considered to represent the neurological state of affairs underlying this ability.

Updating (WM) was referred to by nine texts. Of these, five were assessment measures. It most often associated with fluency tasks (e.g., '*From the moment he starts responding, he must constantly compare the responses that he has made to those that still* *remain to be carried out… the self-ordered test makes considerable demands on an active, working memory',* Petrides & Milner, 1982, p. 260).

Surprisingly, only four texts referenced the overlap of EF with gF (e.g., '*Tests of fluid intelligence that require novel problem-solving inevitably do test some aspects of executive skills…*', Andrewes, 2015, p. 200). Of these, only one chapter (Hunter & Sparrow, 2012) highlighted the role of WM in moderating this association.

Influence [of EF] on source memory was described by six texts. Texts particularly referred to this category within the context of 'dysexecutive' symptoms (e.g., '*Patients [with dysexecutive symptoms] may… show poor free recall in contexts where encoding strategies would normally bolster learning and later retrieval…*', Floden, 2014, p. 500). As well as difficulties in attending to information, problems with temporal organisation of information were also considered likely to contribute to the tendency to confabulate, and poor recall among these patients (Gazzaniga et al., 2019).

Of the attentional processes associated with EF, dual task control (e.g., '*to set priorities in the face of two or more competing tasks*', Wilson et al., 1996, p. 4) was mentioned the least (in only six texts). It has been suggested that 'multi-tasking' may not comprise a distinct mental process to task switching (Gazzaniga et al., 2019), with similar deteriorative effects on performance being demonstrated by subjects completing two tasks simultaneously, and when shifting between tasks (Koch et al., 2018). This might reiterate the need for care in task design, to ensure (as far as possible) that it is capturing a unique process; or, further highlights the difficulty in isolating one attentional process from another. The interactivity of attentional processes may also account for the variability in authors' understandings of which mental processes would be recruited by particular tasks. For example, the Stroop test (Stroop, 1935) was discussed both as a measure of task switching ability (e.g., '*… [it] appears to measure a specific higher cognitive function – the ability to shift between conflicting verbal response modes*', Trenerry et al., 1989), and of the ability to suppress a prepotent response (e.g., '*After… years of learning to read words, it is hard to suppress that habit and respond to the color instead [in the Stroop task]',* Kalat, 2017, p. 447). These inconsistencies may be closer to being resolved through a more 'unified' understanding of EF, which can account for the mutual dependency (i.e., 'co-variation') of cognitive processes.

Value of objectivity (n = 3) was identified as a latent category. It was considered that this may have permeated ideas of what 'ideal' EF might look like: e.g., a predominantly cognitive process, resistant to strong emotions and sentiment, while utilising contextual cues to guide and moderate behaviour. It was difficult to accurately quantify this category, given that its presence was more often indicated by the *absence* of (affective) information, than its inclusion (e.g., '*[In order to plan, one must be able to] view the environment objectively (i.e., take the 'abstract attitude')*', Lezak et al., 2012, p. 671). Caution is needed, prior to ascribing any kind of 'rationality' to this 'higher' neuropsychological function. Not only would this present a dry, 'robotic' version of human experience (Barkley, 2012), but 'rationality' is also culturally weighted, linked with political power and the imposition of the *status quo* (Flyvbjerg, 2003).

Affective and motivational processes

Motivational intensity was described in eight texts, both in sequential terms (e.g., as a '*precondition*' of action; Lezak et al., 2012, p. 667), and as a continuous construct, implicated in maintaining behaviour over time (Floden, 2014). Motor regulation (n = 7) and emotion regulation (n = 6) were inductively derived from the texts, mainly from accounts of 'dysexecutive' symptoms (e.g., '*Frontal lobe lesions result in motor dysfunction…*', Grace & Malloy, 2001, p. 1; '*Some stroke patients may yield too easily to emotion, which is referred to as emotionalism*…', Andrewes, 2015, p. 221). Nine texts (six textbooks) acknowledged the <u>reciprocal influence of affect and attentional processes</u>. This was also usually in the context of discussing difficulties with EF (e.g., '*Many [Korsakoff patients] are virtually immobilised by apathy and inertia',* Lezak et al., 2012, p. 666), throwing light on the devastating and disabling impact of 'apathy'. The importance of emotions in conveying information, and influencing motivational and attentional processes, was succinctly summed up by Fiske and Taylor (2020): '*Emotions can control cognition, alerting people to important goals*…' (p. 405).

Conceptual uncertainty

A sixth main category, <u>conceptual uncertainty</u>, and associated subcategory, the <u>necessity for continuing theoretical development</u>, were inductively derived from the texts (e.g., '*…how do we define a nebulous concept like executive function?*', Andrewes, 2015, p. 210).

Discussion

Talking about the consequences of injury to EF, by necessity, requires some understanding of how the uninjured, 'intact' process may operate (Goodglass & Kaplan, 1979). In light of recent evidence on the 'nature' and operation of EF, the current study applied a content analysis to recently published textbooks and currently available assessment measures. The aims were threefold: to systematically explore how EF was narrated and understood in these texts, to compare this understanding with current theory, and to generate new leads in linking its theoretical structure with real-world/clinical application.

Deductive categories were based on the main tenets of the 'unified model' (as introduced in Section A) and current evidence supporting a more 'continuous' conceptualisation of EF. Only three textbooks touched on every overarching category (Andrewes, 2015; Cozolino, 2017; Floden, 2014), indicating that the majority of texts did not include such an integrated account. Frequency counts potentially reflected a prevailing reliance, especially amongst assessment tools, on older laboratory-based tasks to 'explain' EF (i.e., in terms of categorical attentional processes), rather than a more systemic conceptualisation routed in the interactivity of affective and cognitive processes.

Within the broad remit of 'facilitation of goal-directed behaviour', 'planning' and 'effectively responding to feedback', were popularly cited among attempts to define EF. 'Adaptation to novel situations', offered a definition that appeared coherently linked with the mental process of 'task switching', cognitive flexibility, and gF (Cañas et al., 2003; Santarnecchi et al., 2017).

Inductive categories provided an opportunity to 'mine' the texts for additional information that could shed further light on understanding of EF. The 'unified model' of EF was thought likely to benefit from incorporating the influences of additional variables: namely, 'chronoception' (the subjective experience of time), and externally generated feedback. There is currently a lack of data to indicate the directionality of associations between chronoception, memory, and motivational/affective processes; though discussions have begun considering their associated impact on the experiences of people with learning disabilities. In particular, increasing time perception was suggested to improve feelings of self-efficacy within this client group (Owen & Wilson, 2006), which may indicate a positive correlation between time perception and motivation (Dixon et al., 2007), and, potentially, a target for treatment.

Strengths and limitations

More than other methods, content analysis requires a tolerance of uncertainty, which may have made it a particularly fitting choice for examining EF (Glaser, 1978; Elo & Kyngäs, 2008). Uncertainty was managed through self-reflexivity, and close adherence to Assarroudi et al.'s (2018) three-phase approach to capturing and evaluating data. However, the inherent conflict between the inductive and deductive approaches potentially resulted in each being 'tainted' by the other (i.e., can categories be entirely 'inductively' derived following the 'priming' effect of introducing an evidence-based model?). Despite this, the analysis yielded a wealth of information from the texts, including uncovering promising new leads for continued theoretical development, and for neurorehabilitation.

Clinical implications

Assessment

Co-variation of mental processes, and uptake of compensatory strategies, may help to explain the variable test-retest reliability, and poor generalisability of performance-based measures of EF (Barkley, 2012; Soveri et al., 2018; Toplak et al., 2013). The tension present when developing neuropsychological assessment tools is that they be as practical as possible to administer, while also comprehensively assessing the construct(s) of interest (Burgess, 2021). In the case of EF, there are risks associated with swinging too far towards 'practicality', with some manuals even suggesting that use of single subtests may be adequate in certain conditions (e.g., Stern & White, 2003). Given the disintegrative, ‘ripple’ effect of injury to EF, this seems unlikely to be the most helpful approach. Burgess (2021) and Jurica et al. (2001) reiterated the importance of testing a range of cognitive skills, which would provide the necessary data to identify the extent of intra-individual variation (i.e., measure of cognitive dispersion; Sorg et al., 2021). However, more work is needed to consider the various cut-off scores that would distinguish pathological variation from that which occurs in the healthy population (Burgess & Alderman, 2013). Qualitative aspects of performance (i.e., *how* an individual approaches the test) can also provide essential clues as to the integrity of EF (Floden, 2014).

Intervention

Evidence suggests that compensatory strategies for EF can be either internally or externally driven. Effective internal strategies may include ‘self-talk’ (though this can be carried out aloud; Floden, 2014), drawing from Vygotsky (1962) and Luria’s (1961) ideas regarding the contribution of ‘inner speech’ to ‘self-regulation’. Related to this, the effect of ‘self-talk’ in interpreting emotional experience (i.e., ‘cognitive reappraisal’) can influence both immediate affect, and long-term memories of events (Fiske & Taylor, 2020): essentially targeting multiple ‘nodes’ within the circuitry of EF. However, this also depends on the degree to which the individual is able to ‘switch’, and ‘sustain’ attention (either directing it inwards, ‘detaching’ from external stimuli, or vice versa; Cozolino, 2017). Mindfulness-based training has been recommended in helping to amplify awareness of ongoing mental processes, enabling the selection (and suppression) of certain activities (Siegel, 2007). Lastly (returning to ‘chronoception’), external cues in the form of diaries/timetables were described as some of the ‘most popular’ compensatory strategies in externalising individuals’ ‘sense of control’, helping them to self-monitor and prompt their behaviour when needed (Andrewes, 2015, p. 216).

Research implications

A ‘unified’, or integrated model, is essential to progressing understanding of EF, and avoiding becoming ‘stuck’ in the ongoing absence of a fully operational definition (Barkley, 2012). A reduction (or standardisation) of terminology would help to facilitate the continued development of an integrated model, provide greater opportunity for synthesising findings across studies, and potentially reduce jargon in assessment feedback sessions (Brenner, 2003). An important area for further research would be the testing and refinement of assessment processes used in conjunction with measures of ‘cognitive dispersion’ (Sorg et al., 2021), and determining the sensitivity and specificity of these measures to EF-related deficits. The construct of ‘chronoception’ is also in need of elucidation; particularly with regard to its links with motivation and/or apathy.

Conclusion

It was acknowledged that the premise of localisation, which underpins many popular neuropsychological assessments (Chan et al., 2008; Ruff, 2003), was likely to be outdated in relation to understanding EF, which evidence suggests is instead supported by neural circuitry across multiple brain regions. This more systemic conceptualisation also appears compatible with the idea of EF as a predominantly continuous construct in a healthy brain (Burgess, 2021). Drawing on these findings, as well as the preliminary ‘unified model’ introduced in Section A, a categorisation matrix was developed as a method of evaluating currently available assessments and textbooks on EF, to analyse how far the information contained reflected current evidence on EF. Of the 29 texts analysed, only three textbooks referred to every category in the matrix (Andrewes, 2015; Cozolino, 2017; Floden, 2014). This suggested that a more integrated account of EF remains unusual and is yet to be fully incorporated into both theoretical (i.e., textbooks) and clinical resources in the field.

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Section C

Appendix I. Frequency table for categories and subcategories.

Main categories	Subcategories	Frequency count	Sample meaning units
Structural and functional integration	Integration of cortical and subcortical systems	Measures (n = 0) Textbooks (n = 14) Total: 14	**<u>Measures</u>** None. **<u>Textbooks</u>** *'…[EF]…is subserved by an intricate network of neural resources.'* (Hunter & Sparrow, 2012, p. 12). '*…there is clear evidence that [executive dysfunction] can be observed subsequent to other types of neural insult, including subcortical and cerebellar damage.*' (Hunter & Sparrow, 2012, p. 12). '*The neural systems supporting EF are complex and widely distributed, integrating the PFC with the brainstem, cerebellum, pons, and wider cortex, as well as the networks within the limbic system and routing through subcortical structures…*' (Hunter et al., 2012, p. 47) *'The limbic system is intimately connected with the PFC and broader cortical and subcortical structures, and as a result, is involved in the regulation and support of EF.*' (Hunter et al., 2012, p. 52) *'This [localisation] model failed to account for evidence of intact functioning after removal of the frontal lobe, experienced after damage to other brain areas, or evidence of [executive dysfunction] in the absence of a known neurologic insult (as is the case with some of the neurodevelopmental disorders).*' (Hunter & Sparrow, 2012, p. 5)

			‘*Subcortical as well as cortical damage can impair executive behaviour.*’ (Lezak et al., 2012, p. 666) ‘*Korsakoff patients with lesions primarily in subthalamic nuclei and other subcortical components of the limbic system typically exhibit profound disturbances in executive behaviour.*’ (Lezak et al., 2012, p. 666) *‘Different regions of prefrontal cortex seem to be functionally connected with eachother, and also to regions outside the frontal lobes…it is unlikely to be possible to simply map cognitive ability A to brain region X.*’ (Burgess & Alderman, 2013, p. 216). ‘*…a model of distributed neural networks with nodal points more specialized for certain function has supplanted the idea of particular brain centers.*’ (Larner, 2013, p. 1) *‘The back of the brain has the sections of the orchestra…the front of the brain is the conductor. The conductor stops and starts the orchestra…’* (Postal & Armstrong, 2013, p. 77) ‘*The functional specificity of the frontal lobes is also reflected in connections with subcortical regions. Distinct fronto-striato-thalamo-cortical networks have also been described…*’ (Floden, 2014, p. 508) ‘*…frontal abilities are more accurately conceived of as the result of processing within networks or circuits and therefore, the [brain] regions discussed…should always be considered in the context of their connectivity to other brain regions.*’ (Floden, 2014, p. 499)

			'…the frontal lobe is well-placed to carry out a controlling, teleological role by virtue of its multitudinous connections with other areas of the brain…' (Andrewes, 2015, p. 201) '*Subsequent work has expanded this [frontal circuitry] to include other brain regions as well, such as the medial prefrontal and parietal cortices*.' (Keshavan, 2015, p. 30) '*Broadly, cortical pathways connecting frontal executive circuits to phylogenetically older limbic regions of the brain are now known to support many of these social cognitive abilities.*' (Keshavan, 2015, p. 30) *'…the prefrontal cortex receives input via connections from the amygdala, dorsomedial thalamus, sensory association cortex, posterior parietal cortex, and the dopaminergic cells of the ventral tegmental area…'* (Kolb et al., 2016, p. 419) *'The impulse to localize functions to one area of the brain is evolving into more sophisticated strategies that explore interactive networks distributed throughout the brain and nervous system*.' (Cozolino, 2017, p. 120) *'[The frontal lobes'] organization and connectivity provide for the integration of input from the entire brain.*' (Cozolino, 2017, p. 122)

			'…studies have altered the long-held prevailing view of separate neuroanatomical modules in favor of dynamic, interconnected areas and circuits.' (Clark et al., 2018, p. 87) *'Cognitive control requires the integrated function of many different parts of the brain.'* (Gazzaniga et al., 2019, p. 516) *'The PFC also receives huge input from the thalamus, relaying information from the basal ganglia, cerebellum and various brainstem nuclei.'* (Gazzaniga et al., 2019, p. 517) '*The activity in the PFC brain regions signals other brain structures that guide the flow of activity along neural pathways and establish mappings between inputs of internal states and outputs needed to perform a particular task (E. K. Miller & Cohen, 2001).*' (Fiske & Taylor, 2020, p. 443) *'…it has become clear that executive functions depend not only on frontal cortical areas but also on many other brain areas that are linked…through larger executive control networks.'* (Kolb & Whishaw, 2021, p. 404)
	Specialised networks	Measures (n = 1) Textbooks (n = 10)	**<u>Measures</u>** *'…the dorsolateral prefrontal circuit has been associated with executive cognitive dysfunction; the orbitofrontal prefrontal circuit has been associated with disorders of self-regulation…; and the anterior cingulate circuit has been associated with disorders of activation, spontaneous behavior, and motivation…'* (p. 2, Grace & Malloy, 2001)

		Total: 11	<u>**Textbooks**</u> *'Research to date strongly suggests that <u>principal domain controls</u> are best associated with the PFC and its component structures…'* (Hunter et al., 2012, p. 49) *'The ventrolateral prefrontal cortex (VLPFC) and posterior PFC (including areas in and around the inferior frontal sulcus) have been implicated in rule acquisition, rule switching, inhibition of competing responses, and aspects of WM.'* (Hunter et al., 2012, p. 50,) '…*an abstract vs. sensory-based processing in the rostral-caudal axis [of the PFC].*' (Floden, 2014, p. 505) *'…some networks do seem, at present, to function in a general way in terms of selective attention (ventrolateral areas), conscious deliberation (medial area), emotional and social evaluation (anterior ventral areas) and cognitive manipulation (dorsolateral areas)…*' (Andrewes, 2015, p. 210) *'…the parietal cortex, especially within the right hemisphere, also contributes to focused attention and with frontal areas allows for flexible switching and allocation of attention to items represented internally…*' (Andrewes, 2015, p. 252) '*At this stage it is safest to say that pre-supplementary motor area (pre-SMA) and the supplementary motor area (SMA) and also the middle cingulate below these areas…are part of a network that is important to initiation and inhibition of motor response…More specifically, this network also includes*

			a pathway via the caudate nucleus and the globus pallidus (parts of the basal ganglia), and then the thalamus, prior to returning to the cortex…' (Andrewes, 2015, p. 224) *'…the connections [between area 10] with other brain areas allow this area [that appears to be responsible for metacognition] to integrate and influence the final product of the sensory inputs and memory retrieval*.' (Andrewes, 2015, p. 215) '*Multitasking does seem to be dependent on the integrity of PFC regions…*' (Andrewes, 2015, p. 214) '*More caudal areas of the PFC may act independently when more rostral areas of the PFC are not required according to less complex requirements of the task* (context).' (Andrewes, 2015, p. 257) '*…when more complex processing is required there is a one way hierarchical influence of more rostral areas on more caudal areas*.' (Andrewes, 2015, p. 257) *'…the anterior or rostral mid-cingulate (rMACC) is associated with what Don Stuss calls energisation [see Stuss & Alexander, 2007] and others have described as a drive…this area may be most important to self-initiated purposeful mentation.*' (Andrewes, 2015, p. 235) *'…self-reflective processing involves the activation of midline cortical structures (e.g., medial PFC and posterior cingulate cortex) as well as parts of the lateral temporal cortex…*' (Keshavan, 2015, p. 32) '*The prefrontal cortex contributes to specifying the goals toward which movement should be directed. It controls the processes by which we select movements appropriate to the particular time and context*.' (Kolb et al., 2016, p. 419)

			‘*…the frontal lobes act much like a composer, but instead of selecting notes and instruments, they select our actions.*’ (Kolb et al., 2016, p. 415) ‘*While both areas play a role in action and inhibition, the [dorsolateral PFC] and [orbitomedial PFC] specialize in attentional and social-emotional tasks, respectively.*’ (Cozolino, 2017, p. 126) ‘*…[salience network:] the anterior cingulate cortex (ACC) and anterior insular (AI) appear to segregate information and direct attention to the most relevant internal and external stimuli to guide our emotional and interpersonal responses to others.’* (Cozolino, 2017, p. 134) ‘*Projections [to the PFC] from the parietal regions contain integrated visual, motor and vestibular information, while those from the temporal lobe transmit sensory information that has already been synthesized with socioemotional appraisal.*’ (Cozolino, 2017, p. 122) ‘*A component of the integration of top-down, cortical and limbic processing occurs in the communication between the orbitomedial PFC and dorsolateral PFC…In addition, the dorsal and lateral areas of the frontal cortex network with the hippocampus while the medial regions become densely interwoven with the amygdala…*’ (Cozolino, 2017, p. 133) ‘*Deliberate, top-down direction of attention depends on parts of the prefrontal cortex and parietal cortex…*’ (Kalat, 2017, p. 446)

			'...output of the pre-SMA [pre-supplementary motor area] and SEF [supplementary eye field] is to the DLPFC. The pre-SMA and SMA appear to be involved in executive control in situations of anticipation, errors, and response conflict...' (Clark et al., 2018, p. 78) '*A group of special 'hyperdirect' fibers from both the pre-SMA and SMA project directly to the subthalamic nucleus of the basal ganglia. Activation of these fibers would rapidly 'brake' any ongoing activity in the cortical-basal ganglia circuit…*' (Clark et al., 2018, p. 78) '*Some regions, such as the DLPFC, are primarily executive cognitive in function and are interconnected with parietal and temporal association areas…'* (Clark et al., 2018, p. 80) *'…regions, such as VMPFC and OFC, are primarily socioemotional and interconnected with limbic areas such as the insula and the amygdala…Output…also takes an indirect route to limbic and other areas via the ACC'* (Clark et al., 2018, p. 80) *'The first system, which includes the lateral PFC, orbitofrontal cortex, and frontal pole, supports goal-oriented behavior...is involved with planning; simulating consequences; and initiating, inhibiting and shifting behavior.'* (Gazzaniga et al., 2019, p. 517) *'The second control system, which includes the medial PFC, plays an essential role in guiding and monitoring behavior…monitoring ongoing activity to modulate the degree of cognitive control needed to keep behavior in line with current goals.'* (Gazzaniga et al., 2019, p. 517) *'…[Lateral PFC] activation reflects a representation of the task goal and as such, serves as an interface with task-relevant long-term representations in other neural regions...'* (Gazzaniga et al., 2019, p. 523)

			'Three gradients have been described to account for PFC processing differences: ventral-dorsal [i.e., maintenance and manipulation, respectively], anterior-posterior [abstract intent to concrete movement], and lateral-medial [external cues to internal motivation].' (Gazzaniga et al., 2019, p. 525) '*…the basal ganglia are implicated in response initiation…the subthalamic nucleus [STN] provides a strong excitatory signal to the globas pallidus, helping to maintain inhibition of the cortex…the right PFC [right inferior frontal gyrus] generates the command to abort a response, and this…is carried out through recruitment of the STN.'* (Gazzaniga, 2019, p. 550) '*The medial frontal cortex (MFC) including the anterior cingulate cortex (ACC) is thought to be a critical part of a monitoring system, identifying situations in which cognitive control is required...'* (Gazzaniga et al., 2019, p. 563) '*The medial frontal cortex (MFC) is hypothesized to work in tandem with the rest of the prefrontal cortex, monitoring ongoing activity so it can modulate the degree of cognitive control...'* (Gazzaniga et al., 2019, p. 564) *'A…salience network is seen in correlated activity among the anterior cingulate cortex [ACC], supplementary motor cortex, and anterior insular cortex…the salience network is most active when there are external (environmental) stimuli that are particularly significant and a behavioral change is needed…'* (Kolb & Whishaw, 2021, p. 400) '*…central role of three components: interhemispheric dorsolateral frontal connections, a dorsolateral frontal-parietal subnetwork, and frontal-striatal connections (Shen et al., 2019).'* (Kolb & Whishaw, 2021, p. 404)

	Lateralisation *(Inductive)*	Measures (n = 3) Textbooks (n = 7) Total: 10	**Measures** *'It may be the case that an active working memory is more critically dependent on the left frontal cortex than the right, perhaps because some degree of verbal mediation may be necessary to this process.'* (Petrides & Milner, 1982, p. 260) *'…patients with right frontal and right fronto*-*central lesions were more impaired on tasks of design fluency than those with left frontal lesions.'* (Ruff, 1996, p. 1) *'Language occurs predominantly in the left hemisphere, and visuo-spatial/perceptual analysis occurs predominantly in the right hemisphere.'* (Burgess, 2021, p. 52) **Textbooks** *'…patients with right hemisphere damage who can 'talk a good game' and neither inert nor apathetic may be ineffective because limitations in organising conceptually all facets of an activity and integrating it with their behavior may keep them from carrying out their many intentions.'* (Lezak et al., 2012, p. 666) *'There is also good evidence for hemispheric specialisation for the lateral areas [of the frontal lobes] although the exact nature of left/right differences is debated.'* (Floden, 2014, p. 509)

			‘*…the parietal cortex, especially within the right hemisphere, also contributes to focused attention and with frontal areas allows for flexible switching and allocation of attention to items represented internally…*’ (Andrewes, 2015, p. 252) ‘*These connections [from the orbitomedial PFC] and their bias towards the right hemisphere, are associated with processing social information and emotional experience*.’ (p. 126, Cozolino, 2017) ‘*Like the right and left hemispheres with which they are linked, the ompfc and dlpfc can demonstrate various degrees of integration and dissociation.*’ (Cozoloino, 2017, p. 126) *‘With more left-sided DLPFC involvement [in a lesion], there is a reduction in verbal fluency or the ability to search for words within a semantic category… With more right-sided DLPFC involvement, there is a reduction in design fluency or the ability to create designs…’* (Clark et al., 2018, p. 82) *‘Increasing the personal relevance of stimuli and the intensity of approach motivation, especially, increases left frontal activation, consistently tied to positive and approach motivational affect, whereas right frontal activation associates with negative or withdrawal motivational affect (Harmon-Jones et al., 2006).’* (Fiske & Taylor, 2020, p. 449) *‘…the left frontal lobe appears to be involved in task setting, whereas the right frontal lobe is more involved in task monitoring.’* (Kolb & Whishaw, 2021, p. 404)

	Continuous construct (in healthy population)	Measures (n = 2) Textbooks (n = 3) Total: 5	**Measures** '*D-KEFS process measures that often yield attenuated distributions in normally functioning examinees and higher ranges and distributions in certain clinical populations include error rates, contrast scores and ratio measures*.' (Delis et al., 2001, p. 17) *'...cognitive functions that may correlate in the intact brain – thereby giving the illusion of a unitary construct...*' (Delis et al., 2001, p. 53) *'It may be that most cognitive functions operate collectively, seamlessly, undetectably, unitarily – until something goes wrong in the brain.'* (Burgess, 2021, p. 40) **Textbooks** *'Efforts to examine construct validity generally find that performance on tests hypothesized to measure EF is moderately correlated with many other constructs, not just EF (i.e., low discriminant validity).*' (Hunter & Sparrow, 2012, p. 5) '*…many of the symptoms of executive dysfunction are seen occasionally in the healthy population, albeit perhaps under special circumstances, and in a milder form, such as confabulation, impulsivity and disinhibition…therefore it is often the extremeness of the behavioural sign than its type that is at issue…'* (Burgess & Alderman, 2013, p. 213).

			‘*…The idea that different executive skills might depend on common and general underlying operations is encouraged by the finding that seemingly different tasks are associated with the same pattern of fMRI activation…*’ (Andrewes, 2015, p. 209) ‘*The distinction between episode and branching [i.e., maintaining rules over time] seems to be one of degree of resource required.*’ (Andrewes, 2015, p. 256)
	Categorical construct *(Inductive)*	Measures (n = 3) Textbooks (n = 5) Total: 8	**<u>Measures</u>** ‘*…it seems likely…[EF] is composed of a number of different processes or systems which can be impaired singly or in combination in any one patient.*’ (Burgess & Shallice, 1997, p. 4) ‘*…the relatively low positive correlations between D-KEFS tests indicate that the instruments are not interchangeable and measure unique aspects of executive functioning, with some overlap in variance.*’ (Delis et al., 2001, p. 82). ‘*Cognitive skills are known to be both, unitary and able to be compartmentalised, labelled and measured.*’ (Burgess, 2021, p. 40) **<u>Textbooks</u>** ‘*Another key assumption in early work regarding EF was that there is a homogenous executive construct. This <u>oversimplification</u> led to a substantial degree of inflexibility in planning, executing, and interpreting studies.*’ (Hunter & Sparrow, 2012, p. 5)

			'Each [component of EF, i.e., 'volition', 'planning and decision-making', 'purposive action' and 'effective performance'] involves a distinct set of activity-related behaviors...' (Lezak et al., 2012, p. 666) *'The study of patients with smaller lesions…has supported the view that the frontal lobes are involved in a broad range of more discrete functions…'* (Floden, 2014, p. 503) '*The proposal for fractionation of executive function becomes more supported…*' (Andrewes, 2015, p. 200) *'…important distinction…between cognitive functions related to the dorsolateral prefrontal cortex and emotional functions related to the ventral medial prefrontal and orbitofrontal regions.'* (Kolb & Whishaw, 2021, p. 404) '*There is not a single executive system, but there are likely multiple executive subsystems that are anatomically and behaviourally separate.*' (Kolb & Whishaw, 2021, p. 404)
	Disintegration (in the event of illness/injury)	Measures (n = 2) Textbooks (n = 3)	**Measures** '*…certain homogeneous patient groups such as those with focal brain lesions may…[exhibit] test performances that are best captured by [particular] process measures [e.g., frequency of errors]…such patient samples are likely to provide more extensive ranges of raw scores for these variables…' (p. 17, Delis et al., 2001)*

		Total: 5	*'…[cognitive functions which appear unitary] can dissociate in the damaged brain, but only if the pathology occurs in brain regions known to disrupt vital cognitive processes tapped by the neuropsychological tests.*' (p. 53, Delis et al., 2001) *'…executive dysfunction (e.g., cognitive and behavioral disorganization…)*' (p. 1, Grace & Malloy, 2001) **Textbooks** '*Executive functions can break down at any stage in the behavioral sequence necessary for planned or intentional activity.*' (Lezak et al., 2012, p. 666) '*Patients who have trouble programming activity may display a marked dissociation between their verbalized intentions and their actions.*' (Lezak et al., 2012, p. 684) *'[Symptoms of DEX]: Knowing-doing dissociation…*' (Burgess & Alderman, 2013, p. 212). *'…virtually all leading theorists now subscribe to the view that some functions of the frontal lobes can be impaired singly or in combination…*' (Burgess & Alderman, 2013, p. 216). *'Factor analysis of these symptoms [reported on the Dysexecutive Questionnaire; Burgess et al., 1998] revealed a five factor solution, suggesting a fractionation of the dysexecutive syndrome…'* (Burgess & Alderman, 2013, p.217). *'…many impairments can be seen in isolation…*' (Burgess & Alderman, 2013, p. 219).

			'Current thinking favors the view that these [dysexecutive] syndromes should not be viewed as singular clinical entities but rather as compilations of impairments that arise from damage to multiple areas.' (p. 503, Floden, 2014)
	Homunculus fallacy *(Inductive / latent)*	Measures (n = 0) Textbooks (n = 4) Total: 3	**Measures** None. **Textbooks** **'***The back of the brain has the sections of the orchestra…the front of the brain is the conductor. The conductor stops and starts the orchestra…'* (Postal & Armstrong, 2013, p. 77) *'… the salience network serves to direct the focus of our attention to either the inner or the outer world, and toward the experience of others or ourselves.'* (Cozolino, 2017, p. 134) *'…the frontal lobes act much like a composer, but instead of selecting notes and instruments, they select our actions.*' (Kolb et al., 2016, p. 415) *'…the frontal lobe is well-placed to carry out a controlling, teleological role by virtue of its multitudinous connections with other areas of the brain…*' (Andrewes, 2015, p. 201) '*Intuitively…[prospective] memory is also required in multi-tasking. You have to do one task A, but your supervisory attentional system taps you on the shoulder and says 'Don't forget task B.*' (Andrewes, 2015, p. 214).

			'…the connections [between area 10] with other brain areas allow this area to integrate and <u>*influence the final product*</u> *of the sensory inputs and memory retrieval.*' (Andrewes, 2015, p. 215)
Ability to engage in goal-directed behaviour	Planning	Measures (n = 4) Textbooks (n = 9) Total: 13	<u>**Measures**</u> *'…the WCST can be considered a measure of 'executive function', requiring the ability to develop and maintain an appropriate problem-solving strategy across changing stimulus conditions in order to achieve a future goal (Luria, 1973; Shallice, 1982).'* (Heaton et al., 1993, p. 1) *'[Patients with EF deficits] were unable to act effectively on their own initiative.*' (Wilson et al., 1996, p. 4) *'…[In the Action Program Test] one has to work backwards, working out what needs to be done before concentrating on how that end is achieved.'* (Wilson et al., 1996, p. 5) *'…[The Key Search Test] enables us to examine the subject's ability to plan an effective and efficient course of action...'* (Wilson et al., 1996, p. 6) *'It is envisaged that comparison of performance on the two trials [on the Zoo Map Test] will permit quantitative evaluation of…planning ability when structure is minimal versus…when structure is high…'* (Wilson et al., 1996, p. 6) *'Planning problems [subscale of DEX].*' (Wilson et al., 1996) *'[EF difficulties]…may include difficulties with devising and following plans…*' (Burgess & Shallice, 1997, p. 4)

			'[The Mazes subtest measures] planning...' (Stern & White, 2003, p. 10) *'[The Judgement subtest measures] judgement and decisional capacity about issues and situations likely to be encountered in daily living.*' (Stern & White, 2003, p. 10) **<u>Textbooks</u>** *'…[EF] can be conceptualized as having four components: (1) volition; (2) planning and decision-making...'* (Lezak et al., 2012, p. 666) '*In order to plan, one must be able to conceptualize changes from the present circumstances (i.e., look ahead)…*' (Lezak et al., 2012, p. 671) *'The term 'executive functions' refers to those cognitive abilities that enable a person to determine goals, formulate new and useful ways of achieving them…*' (Burgess & Alderman, 2013, p. 209). *'[Symptoms of DEX]: Planning problems…*' (Burgess & Alderman, 2013, p. 212). '*… planning, problem solving, initiation of behaviours…*' (Coetzer, 2013, p. 20) *'The term executive function is used to encompass various cognitive abilities, including the formulation of goals; organization, planning …'* (Larner, 2013, p. 10)

			‘*The dysexecutive syndrome is characterized by difficulties in executing complex goal-directed behaviour due to problems with organization, planning, sequencing, and strategy selection or implementation.*’ (Floden, 2014, p. 500) ‘*There is…some indication of self-determination and creativity embodied in this concept…*’ (Andrewes, 2015, p. 200) *‘...self*-*initiated flexible planning…*’ (Andrewes, 2015, p. 200) ‘*…a supervisory metacognitive level of consciousness that breaks in and reminds us of what our goals and intentions are...*’ (Andrewes. 2015, p. 212) ‘*The executive brain contains the control mechanisms that enable us to…act in an organized and purposeful way*.’ (Cozolino, 2017, p. 121) ‘*…a primary task of the prefrontal cortex appears to be representing goals and the means to achieve them for top-down regulation of activity*.’ (Fiske & Taylor, 2020, p. 447) *[Executive functions are generally considered cognitive processes such as]…planning…problem-solving…’* (Kolb & Whishaw, 2021, p. 403)

	Adaptation to novel situations	Measures (n = 1) Textbooks (n = 4) Total: 5	**<u>Measures</u>** *'…[patients with frontal lobe damage can be] well able to work along routine lines [but] cannot learn to master new types of tasks [p. 22, Rylander (1939)].'* (Wilson et al., 1996, p. 4) **<u>Textbooks</u>** '*…executive functions are intrinsic to the ability to respond in an adaptive manner to novel situations…*' (Lezak et al., 2012, p. 666) *'Exploratory behaviours*' (Lezak et al., 2012, p. 668) '*Overlearned, familiar, routine tasks are expected to be much less vulnerable to impaired brain functioning than are non-routine or novel activities…'* (Lezak et al., 2012, p. 683) *'…and then follow and adapt this proposed course in the face of competing demands and changing circumstances, often over long periods of time.'* (Burgess & Alderman, 2013, p. 209) *'Particular emphasis should be placed on asking the interviewee how well they cope with novel situations…*' (Burgess & Alderman, 2013, p. 210) *'…the executive system exists to allow a person to adapt to new ways of behaving.*' (Burgess & Alderman, 2013, p. 215). '*During the problem-solving process a novel task presents itself that may approached from a number of different perspectives and strategies…*' (Andrewes, 2015, p. 200)

			'…organisation of novel activities towards a self-generated and maintained goal.' (Andrewes, 2015, p. 200) *'…the term executive seems an appropriate one for a system that influences other brain areas toward adaptation to novel circumstances…*' (Andrewes, 2015, p. 211) '*The ability to perform these novel actions is often referred to as executive function.'* (Kolb & Whishaw, 2021, p. 403)
	Chronoception (subjective experience of time) *(Inductive)*	Measures (n = 2) Textbooks (n = 6) Total: 8	**Measures** *'…patients with prefrontal damage…are seemingly insensitive to the future.'* (Bechara et al., 1994, p. 8) *'Temporal sequencing problems [subscale of DEX].*' (Wilson et al., 1996) **Textbooks** '*In order to plan, one must be able to conceptualize changes from the present circumstances (i.e., look ahead)…'* (Lezak et al., 2012, p. 671) *'…and then follow and adapt this proposed course in the face of competing demands and changing circumstances, often over long periods of time.'* (Burgess & Alderman, 2013, p. 209) *'[Symptoms of DEX]: temporal sequencing problems…*' (Burgess & Alderman, 2013, p. 212)

			The key symptom here [with DEX] is problems with abstract thinking, which is often accompanied by temporal sequencing deficits (i.e., not being able to remember the correct order of events)…' (Burgess & Alderman, 2013, p. 217) '*…the goals or aims must be maintained over time during the solving of the problem…*' (Andrewes, 2015, p. 200) '*Problems of maintaining goals, dividing one's attention between different activities and self-directing of their own activities may conspire to undermine performance on complex tasks that must be maintained over time.'* (Andrewes, 2015, p. 212) '*…frontal*-*parietal networks support the integration of perception and action over time.*' (Cozolino, 2017, p. 143) *'It is the PFC which…also merges a sense of self, with a past, present, and future…*' (Clark et al., 2018, p. 73) '*Collectively, the goals thus enabled can be described as goal-oriented behavior, frequently requiring the coordination of a complex set of actions that may unfold over an extended period of time.'* (Gazzaniga et al., 2019, p. 516)
	Self-monitoring	Measures (n = 3)	**Measures**

	(Inductive)	Textbooks (n = 6) Total: 9	‘*…the capacity to initiate a sequence of responses in a given situation and to carry them out with constant monitoring of their execution.’* (Petrides & Milner, 1982, p. 1) *‘The subjects must rely on their ability to develop an estimate of which decks are risky and which are profitable in the long run.’* (Bechara et al., 1994, p. 13) *‘Lack of insight and social awareness[subscale of DEX].*’ (Wilson et al., 1996) *‘…[The Key Search Test] can look at the subject’s ability to monitor his/her own performance...’* (Wilson et al., 1996, p. 6) **<u>Textbooks</u>** *‘…[EF] can be conceptualized as having four components [including]… effective performance.’* (Lezak et al., 2012, p. 666) ‘*The other [necessary precondition for volitional behaviour] is awareness of oneself psychologically, physically, and in relation to one’s surroundings*.’ (Lezak et al., 2012, p. 667) ‘*…self-awareness is multi-faceted as it includes physical awareness, an awareness of self and of other persons, and social awareness. Mature self-awareness requires an integrated appreciation…*’ (Lezak et al., 2012, p. 668) ‘*An associated deficit can show up an impaired appreciation of one’s physical strengths and limitations…*’ (Lezak et al., 2012, p. 668)

			'[In order to plan, one must be able to]…deal objectively with oneself in relation to the environment…' (Lezak et al., 2012, p. 671) *'Some patients cannot correct their mistakes because they do not perceive them.'* (Lezak et al., 2012, p. 704) *'[Symptoms of DEX]: Lack of insight…'* (Burgess & Alderman, 2013, p. 212). *'Self-report of executive difficulties is notoriously inaccurate…'* (Burgess & Alderman, 2013, p. 213) *Frontal lobes: … insight*' (Coetzer, 2013, p. 20) *'[In disinhibition syndrome] insight is often impaired to an extent. In most cases…the patient fails to recognise his or her behavior as inappropriate…*' (Floden, 2014, p. 501) *'Lack of awareness of deficit can throw a wrench in rehabilitation efforts because it is difficult to treat an impairment that the patient is not aware of.*' (Floden, 2014, p. 519) *'…part of executive dysfunction is to lack insight into one's own behaviour…*' (Andrewes, 2015, p. 209) *'The supervisory level of awareness connects our activities with the overall plan. This requires the ability to self-monitor…*' (Andrewes, 2015, p. 216) '*Such patients tend not to monitor their behaviour, which results in a too optimistic view of themselves.*' (Andrewes, 2015, p. 243)

			[Executive functions are generally considered cognitive processes such as] self-monitoring…' (Kolb & Whishaw, 2021, p. 403)

	Effective (contextual/ adaptive) response to feedback *(Inductive)*	Measures (n = 5) Textbooks (n = 10) Total: 15	**Measures** *'[The WCST requires] the client to use the examiner's feedback…'* (Heaton et al., 1993, p. 1) *'Patients with [the DES] are likely to…have problems utilising feedback…'* (Wilson et al., 1996, p. 4) *'In both versions of the [Zoo Map Test] the ability of the subject to minimise errors by modifying their performance on the basis of feedback…is assessed.'* (Wilson et al., 1996, p. 6) *'Patients with [the DES] are likely to…behave inappropriately in social situations (Alderman & Ward, 1991).'* (Wilson et al., 1996, p. 4) *'Lack of concern [subscale of DEX].'* (Wilson et al., 1996) *'Unconcern for social rules [subscale of DEX].'* (Wilson et al., 1996) *'Knowledge-response dissociation [subscale of DEX].'* (Wilson et al., 1996) *'[EF difficulties]…may include problems with…inappropriate social behaviour…'* (p. 4, Burgess & Shallice, 1997) *'…executive dysfunction (e.g…loss of hypothesis generation and testing…'* (p. 1, Grace & Malloy, 2001) *'…executive dysfunction…(e.g…loss of foresight and social judgement…)'* (p. 1, Grace & Malloy, 2001)

			‘*Low scores [on the 3-in-1 test] may reflect poor ability to form and/or understand and use concepts (i.e. spatial, colour, object; semantic category) from what is seen.*’ (p. 116, Burgess, 2021) **<u>Textbooks</u>** ‘*The extent to which patients are aware of and responsive to what is going on around them is likely to be reflected in their use of environmental cues.’* (Lezak et al., 2012, p. 668) *‘[EF difficulties may include]…lack of normal adult self-consciousness…childish or crude behaviour…*’ (Lezak et al., 2012, p. 669) *‘[Symptoms of DEX}: social unconcern, lack of concern for others’ feelings, social disinhibition…*’ (Burgess & Alderman, 2013, p. 212). *‘The disinhibition syndrome is a dramatic condition where the patient often seems to lack impulse control or a social filter…*’ (Floden, 2014, p. 500) *‘Utilization Behavior refers to the tendency for a patient to reflexively use stimuli that are available in the environment but not appropriate to the context…*’ (Floden, 2014, p. 501) *‘[In disinhibition syndrome] insight is often impaired to an extent. In most cases…the patient fails to recognise his or her behavior as inappropriate…*’ (Floden, 2014, p. 501) *‘[In disinhibition syndrome]…the patient is often unable to restrain [inappropriate] behaviour despite feedback.*’ (Floden, 2014, p. 501)

			‘*It is as if [the patient with DEX] is driven by the external environment instead of their own goals*.’ (Andrewes, 2015, p. 221) *‘Lack of insight also leads to socially inappropriate behaviour.’* (Andrewes, 2015, p. 243) ‘*…need to understand others’ emotions and intentions and relate them to our own mental states, so that we can make accurate predictions of predictions of our optimum behavior for day-to-day interactions*.’ (Keshavan, 2015, p. 30) ‘*Empathic thinking requires both affect regulation and cognitive flexibility to pull back from the environment, put our own needs aside, and think about the feelings of others…’* (Cozolino, 2017, p. 125). ‘*Often…people with damage of this type [i.e., frontotemporal dementia] do not recognize or respond to other’s reactions…and therefore they show little empathy…*’ (Kalat, 2017, p. 456) ‘*Adapting behavior appropriately to the environmental context is also a PFC function.*’ (Kolb et al., 2016, p. 420) ‘[*The PFC is capable of] a series of operations that are inserted between stimulus and response for reasoning about options and incorporating feedback about outcomes.*’ (Clark et al., 2018, p. 73) ‘*Often [patients with bilateral lesions]…speak or act impulsively, without reflection…*’(Clark et al., 2018, p. 80)

			'…the capacity to suppress immediate, environmentally dependent responses in favor of reasoned, context-dependent decisions…' (Clark et al., 2018, p. 73) *'[Patients with frontal lesions] were not able to…flexibly change [their response] to fit the context in which they found themselves...'* (Gazzaniga et al., 2019, p. 519) *'…many patients with prefrontal damage could…not regulate their behaviour in a contextually appropriate way.'* (Kolb & Whishaw, 2021, p. 404)

Conceptual uncertainty	Necessity for continuing theoretical development	Measures (n = 1) Textbooks (n = 5) Total: 6	**Measures** '*The [Conceptual Flexibility Index] performed somewhat worse than other SPANS-X indices and should be a focus of future SPANS-X development to attempt to rectify this…*' (Burgess, 2021, p. 46) **Textbooks** '*No existing model, neuropsychological test, or neuroimaging approach is adequate to describe this complex domain of capability…'* (Hunter & Sparrow, 2012, p. 13) '*Specifying unique contributions from one particular cortical area to component aspects of EF remains difficult.*' (Hunter et al., 2012, p. 49) *'Despite this challenge in settling on a definition of executive functioning…*' (p. 200, Andrewes, 2015) '*There are often bewildering disagreements between studies that are only resolved to some degree by reviews…*' (Andrewes, 2015, p. 208) *'Do we really know what type of function we are testing, and how do we define a nebulous concept like executive function?*' (Andrewes, 2015, p. 210) '*Many complex challenges continue*…' (p. 37, Keshavan, 2015) '*Executive functioning is a complex evolutionary accomplishment that we are still in the process of understanding.*' (Cozolino, 2017, p. 139) '*…researchers prefer questions that they know how to answer.*' (Kalat, 2017, p. 456)

Attentional processes	Selective attention	Measures (n = 8) Textbooks (n = 14) Total: 22	<u>**Measures**</u> *'The Color-Word task reliably introduces a strong interference effect in which the colour name hinders the verbal report of the colour of the ink.'* (Trenerry et al., 1989, p. 1) '*…the WCST requires…modulating impulsive responding…'* (Heaton et al., 1993, p. 1) *'A qualitative aspect of the patients' performance also supports the idea that immediate consequences influence the performance significantly.'* (Bechara et al., 1994, p. 14) *'…subjects are unresponsive to future consequences, whatever they are, and are thus more controlled by immediate prospects.*' (Bechara et al., 1994, p. 14) '*Defects in temporal integration and attention would fall under this account…'* (Bechara et al., 1994, p. 14) *'Impulsivity [subscale of DEX].*' (Wilson et al., 1996) *'Disinhibition [subscale of DEX].*' (Wilson et al., 1996) *'Disturbed impulse control [subscale of DEX].*' (Wilson et al., 1996) *'Inability to inhibit responses [subscale of DEX].*' (Wilson et al., 1996) *'Distractibility [subscale of DEX].*' (Wilson et al., 1996) *'…[patients with frontal lobe damage can present with] disturbed attention, increased distractibility [p. 22, Rylander (1939)]…'* (Wilson et al., 1996, p. 4)

			'[EF difficulties]…may include…difficulties with maintaining attention…' (Burgess & Shallice, 1997, p. 4) '*The Hayling Test provides a measure of…performance on a response suppression task…*' (Burgess & Shallice, 1997, p. 4) *'…frontal disinhbition (e.g…impulsivity, disinhibition…inability to delay gratification…'* (p. 1, Grace & Malloy, 2001) *'Disnhibition [subscale of FrSBe]'* (Grace & Malloy, 2001) *'[The Mazes subtest measures]…impulse control...*' (Stern & White, 2003, p. 10) *'The [Attention/Concentration Index] measures…sustained and divided attention with response inhibition…'* (Burgess, 2021, p. 5) '*The ACI provides…added observations regarding inhibiting tendencies toward impulsive…ways of responding.*' (Burgess, 2021, p. 21) *Attention and concentration relate to efficient, focused (sometimes divided) and sustained mental activity for the purpose of completing tasks across variable levels of difficulty.*' (Burgess, 2021, p. 109) *'Sustained and Divided Listening (Round 1) – Ability to sustain concentration on a simple listening task (and make a simple motor response), according to a simple rule.*' (Burgess, 2021, p. 110) *'[In Sustained and Divided Listening (Round 1)] Low scores appear to reflect proneness to lapses in concentration, distractibility, and/or poor effort.*' (Burgess, 2021, p. 110)

			<u>Textbooks</u> *‘All of this conceptual activity [necessary for planning] requires a capacity for sustained attention.’* Lezak et al., 2012, p. 671) ‘*Elements of early models continue to be recognized as EF, including inhibition…’* (Hunter & Sparrow, 2012, p. 13) ‘*Inhibitory control has been described as the foundation of EF*…’ (Hunter et al., 2012, p. 54) *‘[Symptoms of DEX]: distractibility, impulsivity, response inhibition problems*…’ (Burgess & Alderman, 2013, p. 212). *‘Impulsivity, while also a behaviour, is, of course, closely related to executive control function: it is, essentially, doing without thinking.*’ (Coetzer, 2013, p. 25) ‘*Attention is thus effortful, selective and closely linked to intention.*’ (Larner, 2013, p. 2). ‘*That happens with people too when the frontal lobe is damaged. They are doing a task, and then see something else, and ‘Ching!’ the new stimulus drives their behaviour*.’ (Postal & Armstrong, 2013, p. 78)

			'…[need to evaluate] sustained attention…' (Floden, 2014, (p. 512) *'…selective attention, the ability to suppress a prepotent response in favor of a more controlled one.'* (Floden, 2014, p. 513) *'Problems of maintaining goals…may conspire to undermine performance on complex tasks that must be maintained over time.'* (Andrewes, 2015, p. 212) *'It is likely that the inhibition is not just a passive suppression of a response but rather a proactive spontaneously initiated restraint…'* (Andrewes, 2015, p. 224) '*Another task that appears to involve inhibition to response…is the Stroop task.'* (Andrewes, 2015, p. 227) '*Selection may be cued by internal information or made in response to the environmental context…[people with injury to the dorsolateral frontal lobe] become overly dependent on environmental cues to determine their behavior.*' (Kolb et al., 2016, p. 419) *'… the salience network serves to direct the focus of our attention to either the inner or the outer world, and toward the experience of others or ourselves.'* (Cozolino, 2017, p. 134) '*Creating an inner world…requires that we are able to sustain focus on our bodies and in our imaginations…In the search for brain-behavior relationships…it rarely occurred to researchers to see what our brains are up to when we are not engaging* with the external world.' (Cozolino, 2017, p. 156)

			‘*…After all your years of learning to read words, it is hard to suppress that habit and respond to the color instead [in the Stroop task].*’ (Kalat, 2017, p. 447) ‘*Environmental dependency implies a disorder in personal autonomy and indicates that the normal PFC cortex is inward-oriented and overcomes pre-potent, automatic responses to the outside world.*’ (Clark et al., 2018, p. 80) ‘*Inhibition can help prevent distraction and support the focusing component of selective sensory attention.*’ (Clark et al., 2018, p. 86) *‘[Patients with frontal lesions] may be…distractible, or impulsive...’* (Gazzaniga et al., 2019, p. 519) *‘Goal*-*oriented behavior requires selecting task-relevant information and filtering out task-irrelevant information.’* (Gazzaniga et al., 2019, p. 519) *‘…when multiple sources of information come from the same location, we might selectively enhance the task-relevant information (color in the Stroop test) or inhibit the irrelevant information (the word in the Stroop test).’* (Gazzaniga et al., 2019, p. 545) ‘*Executive functions are generally considered cognitive processes such as attentional control…’* (p. 403, Kolb & Whishaw, 2021)

	Task switching	Measures (n = 9) Textbooks (n = 9) Total: 18	**<u>Measures</u>** '*The Stroop procedure appears to measure a specific higher cognitive function – the ability to shift between conflicting verbal response modes*.' (Trenerry et al., 1989, p. 1) *'The Wisconsin Card Sorting Test (WCST) was originally developed to assess abstract reasoning ability and the ability to shift cognitive strategies…*' (Heaton et al., 1993, p. 1) *'…the RFFT was developed with the aim of providing…information regarding nonverbal capacity for fluid and divergent thinking, ability to flexibly shift cognitive set….'* (Ruff, 1996, p. 1) *'Reductions in rate of fluency appear to be primarily related to inflexibility in processing….'* (Ruff, 1996, p. 1) *'The Rule Shift Cards Test…is a simple measure of ability to shift from one rule to another…'* (Wilson et al., 1996, p. 5) *'Perseveration [subscale of DEX]*.' (Wilson et al., 1996) *'Abstract thinking problems [subscale of DEX]*.' (Wilson et al., 1996) *'[EF difficulties]…may include problems with abstract reasoning…*' (Burgess & Shallice, 1997, p. 4) *The Brixton Test is a rule detection and rule following task.*' (Burgess & Shallice, 1997, p. 4)

			'…executive dysfunction (e.g…loss of abstraction…decreased creativity, and impaired problem-solving abilities…' (p. 1, Grace & Malloy, 2001) '*This subscale [Initiation/Perseveration] assesses the participant's ability to initiate, switch and terminate a specific activity with fluency…*' (Jurica et al., 2001, p. 5) '*Research on the DRS subscales by Vitaliano et al. (1984) indicates that the Initiation/Perseveration subscale does differentiate between controls and individuals with mild dementia*.' (Jurica et al., 2001, p. 14) *'This [Conceptualisation] subscale assesses the ability to abstract, that is, to induce similarities and detect differences among verbal and visual stimuli.'* (Jurica et al., 2001, p. 8) *'[The Categories subtest measures] concept formation, cognitive response set, mental flexibility, generativity…*' (Stern & White, 2003, p. 10) *'[The Word Generation subtest measures] verbal fluency, generativity…*' (Stern & White, 2003, p. 10) '*The [Conceptual Flexibility Index] is a measure of executive functioning with…problem-solving, abstraction, concept formation and sensitivity to cognitive inflexibility and perseveration.*' (Burgess, 2021, p. 22) *'…a particular category of executive function, which SPANS-X labels as 'cognitive flexibility'…*' (Burgess, 2021, p. 58)

			‘*Conceptual flexibility is the ability to think laterally, form verbal and visual concepts, flexibly and generatively consider alternatives, and arrange abstract concepts into superordinate categories.*’ (Burgess, 2021, p. 116) ‘*Low scores [on the Similarities test] may represent poor verbal reasoning ability and/or concrete or literal thinking, poor ability to arrange abstract concepts into broader superordinate categories…and/or inflexible/perseverative thinking.*’ (Burgess, 2021, p. 116) ‘*Low scores [on the 3-in-1 test] may represent an ‘executive’ problem of perseveration, or not being able to shift set, inability to keep generating alternatives, and/or to think flexibly or comprehend abstract concepts.*’ (Burgess, 2021, p. 116) **Textbooks** *[In order to plan, one must be able to]… view the environment objectively (i.e., take the ‘abstract attitude’…)…be able to conceive of alternatives, weigh and make choices, and entertain both sequential and hierarchical ideas necessary...’* (Lezak et al., 2012, p. 671) *With regard to cognitive set shifting, engagement and activation of the PFC is a common finding in the adult literature*.’ (Hunter et al., 2012, p. 51) ‘*Abstract thinking’* (Larner, 2013, p. 10) *‘[Symptoms of DEX]: Perseveration, poor abstract thought*…’ (Burgess & Alderman, 2013, p. 212)

			'The key symptom here [with DEX] is problems with abstract thinking, which is often accompanied by temporal sequencing deficits (i.e., not being able to remember the correct order of events)…' (Burgess & Alderman, 2013, p. 217) *'…an assessment of a dysexecutive patient should include…a general measure of inhibitory activities...'* (Burgess & Alderman, 2013, p. 218) '[*Patients with dysexecutive syndrome may exhibit] mental inflexibility leading to 'stuck in set' or perseverative responses…*' (Floden, 2014, p. 500) *'…[need to evaluate] switching attention…'* (Floden, 2014, p. 512) '*There must, then, be a certain amount of cognitive flexibility in trying out and thinking up different approaches towards a goal or solution…*' (Andrewes, 2015, p. 200) *'…neuropsychological tests of executive function often fail to test the initiative and problem-solving creativity that is assumed to be the hallmark of executive function…'* (Andrewes, 2015, p. 199) '*…Perseveration is…often taken as a sign of poor cognitive flexibility…*' (Andrewes, 2015, p. 211) '*…[The Wisconsin Card Sorting Test measures]…the ability to think in a flexible fashion and be able to relinquish a previous matching strategy and take on a new strategy…*' (Andrewes, 2015, p. 211) *'Some [frontal injury] patients get stuck in a particular way of thinking (perseveration) whereas others have difficulty utilizing abstract concepts (concrete thinking).'* (Cozolino, 2017, p. 128)

			'…the term 'multitasking' may be a misnomer: What we really do is alternate between tasks, and with practice we can become quite proficient in task switching (or so we tell ourselves).' (Gazzaniga et al., 2019, p. 542) *[Executive functions are generally considered cognitive processes such as]…reasoning…abstract thinking…'* (Kolb & Whishaw, 2021, p. 403)
	Value of objectivity *(Inductive / latent)*	Measures (n = 0) Textbooks (n = 2) Total: 2	**Measures** None. **Textbooks** *[In order to plan, one must be able to]…view the environment objectively (i.e., take the 'abstract attitude')…'* (Lezak et al., 2012, p. 671) *[Executive functions are generally considered cognitive processes such as]…reasoning…abstract thinking…'* (Kolb & Whishaw, 2021, p. 403)
	Dual task control	Measures (n = 2)	**Measures** *'[Executive abilities part of everyday activities include] to set priorities in the face of two or more competing tasks.'* (Wilson et al., 1996, p. 4)

		Textbooks (n = 4) Total: 6	*Sustained and Divided Listening (Round 2) – Ability to sustain concentration on a 'divided' listening task (and make a simple motor response), according to a couple of rules held in mind simultaneously.*' (Burgess, 2021, p. 110) *'[In Sustained and Divided Listening (Round 2)] Low scores may reflect difficulty multi-tasking or overloaded attentional capacity.*' (Burgess, 2021, p. 110) **<u>Textbooks</u>** '*… the ability to multi-task.*' (Hunter et al., 2012, p. 51) *'…an assessment of a dysexecutive patient should include…a measure of multitasking ability...*' (Burgess & Alderman, 2013, p. 219). *'Divided attention is a very important function of the lateral prefrontal regions…*' (Floden, 2014, (p. 513) *'Problems of…dividing one's attention between different activities…may conspire to undermine performance on complex tasks…'* (Andrewes, 2015, p. 212)
	Updating (working memory)	Measures (n = 5)	**<u>Measures</u>**

		Textbooks (n = 4) Total: 9	*'From the moment he starts responding, he must constantly compare the responses that he has made to those that still remain to be carried out. In other words. the self-ordered test makes considerable demands on an active, working memory.'* (Petrides & Milner, 1982, p. 260) *'…the taxonomy called 'fluency', therefore, to the ability to utilize one or more strategies that maximise production of responses and at the same time avoid response repetition.'* (Ruff, 1996, p. 1) *'[The Modified Six Elements Test] also taps into prospective memory quite highly, i.e. the ability to remember to carry out an intention at a future time.'* (Wilson et al., 1996, p. 7) *'[The Rule Shift Cards Test is a simple measure of ability to… keep track of the colour of the previous card and the current rule.'* (Wilson et al., 1996, p. 5) *'[EF difficulties]…may include difficulties in situations involving certain forms of memory, e.g. remembering to carry out intended actions at a future time…*' (Burgess & Shallice, 1997, p. 4) *'[Amnesic] patients were impaired in their descriptions of the sorting concepts [on the Sorting Test], which suggests this aspect of the task may have a memory component.*' (Delis et al., 2001, p. 47) **Textbooks** '*WM has been tied to PFC activation throughout the extant literature…*' (Hunter et al., 2012, p. 51)

			'The PFC clearly plays a role in regulating the ability to hold information online in the presence of interference.' (Hunter et al., 2012, p. 52) *'…An assessment of a dysexecutive patient should include…measures of executive memory abilities in the short term (i.e., working memory tests)...'* (Burgess & Alderman, 2013, p. 218). '*Patients [with dysexecutive syndrome] may exhibit poor working memory…*' (Floden, 2014, p. 500) *'Working memory is perhaps the most researched prefrontal function…'* (Floden, 2014, p. 514) '*The Wisconsin Card Sorting Test requires the subject to use their working memory in terms of keeping information regarding previous trials in mind*.' (Andrewes, 2015, p. 211) '*Intuitively…[prospective] memory is also required in multi-tasking. You have to do one task A, but your supervisory attentional system taps you on the shoulder and says 'Don't forget task B*.' (Andrewes, 2015, p. 214). '*Working memory is the ability to keep information in mind, despite distraction or the demands of a second task*.' (Andrewes, 2015, p. 217) *'…[prospective] memory is strongly associated with the rostral PFC area*.' (Andrewes, 2015, p. 214)
	Overlap with gF	Measures (n = 1)	**Measures** *'…[Due to their greater variability in performance], we recommend cautious use of the Hayling and Brixton tests with people who…one has good reason to suspect would fall within the bottom 15% of the population on measures of general intelligence…'* (Burgess & Shallice, 1997, p. 6)

		Textbooks (n = 3) Total: 4	*'…plausible to suggest that the correlations between the Hayling and Brixton [subtests] reported here probably reflect shared age and IQ effects, rather than suggesting a common executive resource for each test.'* (Burgess & Shallice, 1997, p. 13) **<u>Textbooks</u>** '*…opinions regarding whether working memory (WM) is part of EF impact interpretation of high correlations between EF measures and intelligence quotient (IQ) test results that are primarily moderated by the Working Memory Index…*' (Hunter & Sparrow, 2012, p. 6) '*It is also true that some intelligence tests show greater correlative relationships with everyday questionnaires that are designed to measure executive skills when compared to some 'executive' tests…*' (Andrewes, 2015, p. 200) '*Tests of fluid intelligence that require novel problem-solving inevitably do test some aspects of executive skills in a broad and modest way…*' (Andrewes, 2015, p. 200) '*Measures of intelligence are correlated with how efficiently our brains integrate and synthesize information via frontal-parietal cooperation.*' (Cozolino, 2017, p. 147)
	Influence on source memory *(Inductive)*	Measures (n = 1)	**<u>Measures</u>** *'Confabulation [subscale of DEX].'* (Wilson et al., 1996) **<u>Textbooks</u>**

		Textbooks (n = 5) Total: 6	*'[Symptoms of DEX]: Confabulation…'* (Burgess & Alderman, 2013, p. 212). *'…an assessment of a dysexecutive patient should include…measures of executive memory abilities in the…long term (i.e., accuracy of episodic recollection)...'* (Burgess & Alderman, 2013, p. 218) *'…he had no awareness he was confabulating…'* (Postal & Armstrong, 2013, p. 78). *Patients [with dysexecutive syndrome] may have difficulty with temporal or spatial context memory and show poor free recall in contexts where encoding strategies would normally bolster learning and later retrieval…'* (Floden, 2014, p. 500) '*…most cases of memory impairment arising from prefrontal dysfunction are associated with impaired control processes that normally facilitate coding and retrieval.*' (Floden, 2014, p. 516) '*[Associating perseveration with cognitive inflexibility]…may be misleading, since memory impairment also results in an inability to remember feedback or indeed one's own previous response.*' (Andrewes, 2015, p. 211) *'[Patients with frontal lesions] may be unable…to organize and segregate the timing of events in memory, remember the source of their memories...'* (Gazzaniga et al., 2019, p. 519)
Affective and	Emotion regulation *(Inductive)*	Measures (n = 1)	**Measures** *'Euphoria [subscale of DEX].'* (Wilson et al., 1996) *'Aggression [subscale of DEX].'* (Wilson et al., 1996)

motivational processes		Textbooks (n = 5) Total: 6	*'Shallowing of affective responses [subscale of DEX].'* (Wilson et al., 1996) **<u>Textbooks</u>** *'[Symptoms of DEX]: Euphoria, aggression, shallow affect…'* (Burgess & Alderman, 2013, p. 212). *Frontal lobes: … emotion regulation…'* (Coetzer, 2013, p. 20) *'Some stroke patients may yield too easily to emotion, which is referred to as emotionalism…'* (Andrewes, 2015, p. 221) '*…prefrontal areas of the brain (e.g., dorsolateral and orbitofrontal prefrontal cortices) work to regulate the activity of limbic regions [i.e., amygdala] to reduce arousal and lend assignment of importance (sometimes called salience) to emotional experience*.' (Keshavan, 2015, p. 30) *'[Patients with bilateral PFC lesions]…may become irritable.'* (Clark et al., 2018, p. 80)
	Motor regulation *(Inductive)*	Measures (n = 3) Textbooks (n = 4)	**<u>Measures</u>** *'Restlessness/hyperkinesis [subscale of DEX].'* (Wilson et al., 1996) *'Frontal lobe lesions result in motor dysfunction…'* (p. 1, Grace & Malloy, 2001) *'[The Mazes subtest measures]…psychomotor speed...'* (Stern & White, 2003, p. 10)

		Total: 7	**<u>Textbooks</u>** *'[Symptoms of DEX]: Restlessness…*' (Burgess & Alderman, 2013, p. 212). *'[Patterns of cognitive change after frontal injury may include]…akinetic (medial frontal) syndromes…*' (Larner, 2013, p. 10) '*…there is a disconnect between what [an individual with impaired EF] wants to do, and what his motor system ends up doing.*' (Postal & Armstrong, 2013, p. 78) *'…frontal-parietal networks support the integration of perception and action over time.*' (Cozolino, 2017, p. 143) '*Some theorists consider cognition to be a derivative of motor behavior…much of our symbolic and abstract thinking is organized by the visceral, sensory and motor metaphors that permeate our language…*' (Cozolino, 2017, p. 123). '*Given movements are goal-oriented, it makes sense that neural networks controlling movement and those organizing goal-directed behavior would be interwoven in our brains…*' (Cozolino, 2017, p. 151)
	Motivational intensity	Measures (n = 1)	**<u>Measures</u>** *'Apathy [subscale of FrSBe]'* (Grace & Malloy, 2001)

		Textbooks (n = 7) Total: 8	**<u>Textbooks</u>** ‘*Motivation, including the ability to initiative activity, is one necessary precondition for volitional behaviour*.’ (Lezak et al., 2012, p. 667) *‘[Symptoms of DEX]: Variable motivation…*’ (Burgess & Alderman, 2013, p. 212). *‘[Symptoms of DEX]: Apathy…*’ (Burgess & Alderman, 2013, p. 212). *‘[Patterns of cognitive change after frontal injury may include]…apathetic (frontal convexity) …syndromes…*’ (Larner, 2013, p. 10) ‘*Often family members feel that cognitive symptoms are essentially about lack of motivation…addressing the distinction between ‘can’t’ and ‘won’t’ during a feedback session allows a productive conversation to begin.’* (Postal & Armstrong, 2013, p. 77). *‘There is a continuum of apathy severity. At the milder end of the spectrum, a patient may initiate behavior but exhibit motor impersistence or failure to maintain behavior….*’ (Floden, 2014, p. 502) *‘Goal-oriented actions are based on the assessment of an expected reward or value…’* (Gazzaniga et al., 2019, p. 519) *‘[Patients with frontal lesions] may be apathetic…’* (p. 519, Gazzaniga et al., 2019)

			'…hot executive functions…are needed in situations that are motivationally significant.' (Kolb & Whishaw, 2021, p. 404)
	Reciprocal influence of affect and attentional processes	Measures (n = 3) Textbooks (n = 6) Total: 9	**Measures** '*Apathy and lack of drive [subscale of DEX].*' (Wilson et al., 1996) *'…executive dysfunction (e.g…apathy, loss of spontaneity, loss of drive and loss of curiosity…'* (p. 1, Grace & Malloy, 2001) *'…valid and interpretable results depend on the patient's willingness and ability to attend to and work towards the solution of the test items.*' (Jurica et al., 2001, p. 4) **Textbooks** *'Many [Korsakoff patients] are virtually immobilised by apathy and inertia.*' (Lezak et al., 2012, p. 666) '*In extreme cases [of lacking volitional capacity], [patients] may be apathetic, or inappreciative of themselves as a distinct person (much as an infant or young child), or both*.' (Lezak et al., 2012, p. 667) '*Patients with pathological inertia may perceive their errors…yet do nothing to correct them*.' (Lezak et al., 2012, p. 704)

			'*Say you inherit a house, and you walk into the attic – and it's so full of stuff. You feel demoralized, and are like 'I don't even know where to begin.''* (Postal & Armstrong, 2013, p. 77) *'Apathy is a complex phenomenon and can occur in motor, cognitive, and emotional domains.*' (Floden, 2014, p. 502) *'Indeed, mild apathy can be easily mistaken for depression.*' (Floden, 2014, p. 502) '*This broader view of executive function has been guided, in part, by an increasing appreciation of the contribution of emotion and intuition in decision-making.'* (Cozolino, 2017, p. 121) '*Abstract thinking and problem solving are particularly dependent on adequate emotion regulation.*' (Cozolino, 2017, p. 127) '*Characteristically these patients [with bilateral PFC lesions] become apathetic, disinhibited, and dysexecutive… appear unconcerned and exhibit slowness and lack of spontaneity in speech, thought, and emotional expression*.' (Clark et al., 2018, p. 80) '*…the separation [of affect and cognition] is not sustained, for example, by one's lived experience of affect and cognition as occurring in a simultaneous mix, not to mention the neuroscientific evidence*.' (Fiske & Taylor, 2020, p. 383) '*Moods affect a wide range of social cognitions and behaviors.*' (Fiske & Taylor, 2020, p. 383)

			'Cognitive interpretation shapes not only the quality of one's immediate affect but also one's lasting mental representation of the event.' (Fiske & Taylor, 2020, p. 403) '*Emotions can control cognition, alerting people to important goals*.' (Fiske & Taylor, 2020, p. 405) '*Intense emotions do interrupt well-planned, ongoing cognitive activities*.' (Fiske & Taylor, 2020, p. 409)
Limited cognitive resource	Co-variation in utilisation of processes	Measures (n = 0) Textbooks (n = 3) Total: 3	**<u>Measures</u>** None. **<u>Textbooks</u>** '*Attentional resources, which are finite, are devoted to some channels but not to others.'* (Larner, 2013, p. 2) *'[Self-monitoring] may be harder when the task or activity demands all of our attention…*' (Andrewes, 2015, p. 216) '*…it turns out that executive functioning is a group effort.*' (Cozolino, 2017, p. 120) *'Like a tennis doubles team, the orbitomedial PFC and dorsolateral PFC depend on one another's performance for optimal functioning…*' (Cozolino, 2017, p. 133)
	Configuration of best fit	Measures (n = 0)	**<u>Measures</u>** None.

		Textbooks (n = 3) Total: 3	**Textbooks** *'For many functions a homeostasis is sought which has little to do with free will…'* (Andrewes, 2015, p. 210) '*The ongoing interaction between the organism and its environment leads to a state of dynamic equilibrium, termed homeostasis. When an organism's ability to adapt to environmental demands is exceeded, it leads to stress…*' (Keshavan, 2015, p. 33) '*And, as the executive networks engage in different tasks, they reintegrate into different configurations to address the specific tasks at hand (Braun et al., 2015)*.' (Cozolino, 2017, p. 122)
	Neuroplasticity *(Inductive)*	Measures (n = 1) Textbooks (n = 3) Total: 4	**Measures** '*Daily practice sessions greatly reduced the subjects' times to completion over the course of the experiment.'* (Trenerry et al., 1989, p. 1) **Textbooks** '*…we can be certain that the relationship between neuromodulatory pathways and the PFC is dynamic and ultimately contributes to cognitive plasticity as well as skill acquisition*.' (Hunter et al., 2012, p. 57)

			'[Rehabilitation] techniques aimed at restoring function aim to capitalize on brain plasticity either through experience-dependent changes…' (Floden, 2014, p. 517) *'Rehabilitation methods that involve practicing the impaired skills are efforts to use experience to 'rewire' the brain for that activity…'* (Floden, 2014, p. 518) '*Neuroplastic processes related to learning can be harnessed for therapeutic purposes across a wide range of disorders…*' (Keshavan, 2015, p. 35)
	Compensatory strategies *(Inductive)*	Measures (n = 3) Textbooks (n = 4) Total: 7	**Measures** '*Some subjects may attempt to improve their performance…by covering up part of the word in order to reduce the interference effect.*' (Trenerry et al., 1989, p. 4) *'A good subject will develop a strategy to help them deal with the response suppression demands of the task (e.g. looking around the room and picking as responses items that they see)…'* (Burgess & Shallice, 1997, p. 5) *'Responses to one letter only [on Sustained and Divided Listening Task II], not two, may reflect a compensation strategy, managing (well enough) a deficient and overloaded attentional capacity.*' (Burgess, 2021, p. 110) **Textbooks**

			'If planning stops, things can feel overwhelming again. When planning and making accommodations resume, things get better.' (Postal & Armstrong, 2013, p. 80). *'The formulation, execution and monitoring of intentions, plans and actions can be directed by internal or external speech…Some success has been demonstrated using self-talk procedures…*' (Floden, 2014, p. 518) *'External cueing to 'attend' can be very helpful [to] these patients [with dysexecutive syndrome]*.' (Floden, 2014, p. 519) *'…the brain may have slightly different ways of achieving the same functional role so that when a lesion disrupts one pathway, it is then compensated by another pathway with only mild evidence of inefficiency*.' (Andrewes, 2015, p. 208) *'One of the most popular [compensatory strategies]…is to externalise [patients'] control through the habitual use of diaries and workbooks…the habitual use of such materials compensates for their failure to self-monitor and internally prompt their own behaviour…*' (Andrewes, 2015, p. 216) *'Another, more complex approach [to rehabilitation] described by Sohlberg & Mateer (2001) is the learning of metacognitive strategies or self-instructional training.'* '*…for some patients it may be possible to learn and use externally offered compensatory strategies.'* (Spikman, 2017, p. 211)

			‘*…intervention programmes that incorporate metacognitive strategies for planning and problem-solving focusing on everyday problems and functional outcomes have a solid base and are strongly recommended for patients with executive problems…*’ (Spikman, 2017, p. 212)

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Appendix II. Comment regarding End of Study report.

This study was restricted to the analysis of texts available in the public domain, thus waiving the need to seek informed consent. It was therefore exempt from formal ethical review, with no requirement to issue an End of Study report to either Salomons or NHS Ethics Panels, or a Research and Development office within a named Trust.