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COMPREHENSIVE REVIEW

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The role of executive functioning in smoking cessation: A scoping review

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Abstract

Issues: Creating and implementing a plan to successfully quit smoking likely requires executive function (EF) skills such as inhibition, cognitive flexibility, attention and working memory. This scoping review consolidates the research evidence evaluating the role of EF in smoking cessation.

Approach: Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR), researchers and a medical librarian searched PubMed, EMBASE, ERIC, CINAHL and PSYCINFO in June 2022, hand-search in September 2022 using relevant MeSH terms, and an updated search was completed in August 2024.

Key Findings: Fifteen articles were included. Self-regulation was the most frequently evaluated EF across all studies. Performance on measures of impulsivity was most frequently related to successful smoking cessation. Across studies, performance on measures in areas of attention, working memory, cognitive flexibility and higher-level EF was variable as it relates to smoking cessation success. There was considerable variability in the measures used to evaluate EF and definitions of cessation success. Across studies, very little research evaluates higher-level EF.

Implications and Conclusion: Differences in EF and cessation measures make comparisons across studies difficult. Future work is needed utilising common assessment and outcome measures that will improve our understanding of the complex cognitive skills needed for successful cessation. Particular consideration should be given to higher-level EFs including reasoning, planning, problem-solving and decision-making.

KEYWORDS

cognition, combustible tobacco, executive dysfunction, executive function, smoking cessation

Key Points

- The role of executive functioning in smoking cessation has been under-researched.
- Self-regulation was the most studied executive function in prior cessation work.
- Impulsivity was most frequently linked to smoking cessation outcomes.
- Studies test executive functions using varying tools, making comparisons difficult.

1 | INTRODUCTION

As of 2020, nearly one-quarter of the global population was using tobacco in some form [1]. A majority of these adults specifically use some form of smoked tobacco [1]. Globally, approximately 8 million deaths per year are attributed to tobacco-related disease [2]. Despite a desire from most adults to stop smoking, few are successful [3]. Additionally, cessation may be made more difficult by reduced access to resources that aid quitting. Currently, only about one-third of the population has access to comprehensive cessation services that may double the chances of successful cessation [1].

Researchers have theorised many factors that influence successful cessation, including the involvement of executive functions (EF). Adele Diamond's model of EF includes working memory, cognitive flexibility, self-regulation and higher-level EF (i.e., reasoning, problem-solving, decision-making) [4]. EFs are effortful cognitive skills that allow persons to direct their thoughts, behaviours and emotions [5], and researchers theorise that an individual's EF abilities may be related to patterns leading to tobacco use disorders (TUD), including tobacco addiction [6–8]. Specifically, researchers have found that poorer functioning on EF measures of inhibition and working memory are related to behaviours that increase the likelihood of tobacco addiction including craving, dependence, age at smoking initiation and years of chronic smoking [8–11]. While these findings may help us understand patterns of smoking initiation and maintenance, there remains a gap in knowledge of how EF may relate to cessation success. Creating and implementing a plan to successfully quit smoking likely requires EF skills [5]. For example, inhibition skills may be needed to resist cravings or the urge to smoke a cigarette during moments of increased stress. Working memory may work with inhibition skills to recall and hold onto the cessation goal as an individual faces triggers throughout their day. Further, higher-level skills such as problem solving may be needed to create and follow a cessation plan.

Research has shown that chronic tobacco misuse is related to poorer functioning in these domains compared to adults without TUD [12]. Therefore, cessation protocols that proactively support EF skills may be beneficial. Additionally, such protocols may provide additional support for individuals with pre-existing conditions that impact EF [13–17]. Previous work has shown that those with severe mental health diagnoses are more likely to be addicted to nicotine, smoke more heavily, have greater nicotine dependence and show less success when attempting to quit compared to individuals experiencing TUDs without severe mental health diagnoses [14, 18–20]. Yet, current evidence-based cessation protocols do not necessarily account for individuals who may struggle with EF because of pre-existing conditions or from chronic smoking itself.

Traditional smoking cessation programs include a combination of pharmacological and psychological interventions [21]. Pharmacological options may include nicotine replacement treatment and drug-therapy using bupropion and varenicline [21]. Psychological treatments may include 'motivational interviewing, educational strategies, cognitive-behavioural therapy, coping skills training, behavioural skills training, and thought restructuring' [22, p. 619]. Pharmacological treatments are designed to address immediate physiological symptoms that present during cessation efforts. Psychological treatments may address more underlying issues that impede success, including EFs. An overview from García-Gómez et al. [21] reported that a combination of psychological and pharmacological treatments had the potential to double smoking cessation success. However, even for those who receive combined pharmacological and psychological treatment, long-term abstinence may still be difficult to achieve. In a maintenance study conducted by Evins et al. [23], fewer than half (45%) of individuals with serious mental illness maintained continuous abstinence after 52 weeks while receiving combined psychological and pharmacological treatment. Continuous abstinence rates were 3 times lower for those who received psychological treatment alone.

Unfortunately, failure to maintain long-term abstinence is a common problem faced by persons with chronic TUD who want to stop smoking [24]. Previous literature has shown that decreases in EF are related to behaviours that contribute to smoking addiction [6–8]. Additionally, chronic smoking is related to poorer outcomes on measures of EF [6]. Guided by this literature, we theorised that EF might similarly play an important role in cessation success. The aim of this scoping review is to answer the following research question: What is the nature and extent of research evaluating EFs in the context of smoking cessation?

2 | METHODS

2.1 | Data sources and search strategy

Scoping reviews seek to map the nature, dimensions and types of evidence available on a particular project and not likely focused on evaluating the quality of the available evidence, as typical in a systematic review [25]. Given the heterogeneity in studies involving EF to evaluate smoking cessation, a scoping review was deemed the most appropriate method to capture the breadth and depth of research activity in this area. This scoping review followed the Preferred Reporting Items for Systematic reviews and

Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [26]. Key search terms were determined through an iterative process with the first, second and last author, in collaboration with a medical librarian. In June 2022, the medical librarian implemented the search in the PubMed, EMBASE, ERIC-APA-CINAHL and PSYCHINFO databases. This search was updated in August 2024.

2.2 | Eligibility criteria

To be included in this scoping review, articles had to be published in a peer-reviewed journal, in English, and report on a study that measured EF and the impact these skills had on smoking cessation for combustible tobacco. Additionally, articles needed to explicitly include cessation outcome as a primary dependent variable. Combustible tobacco was defined as a cigarette, cigar, cigarillo, pipe, hookah or water pipe. Adele Diamond's model of EF guided this work [4]. This model includes working memory, cognitive flexibility, self-regulation and higher-level EF and is described in depth in a following section. Articles were excluded if they were conference abstracts/dissertations/theses, not evaluating combustible tobacco cessation (e.g., marijuana, cannabis, chewing tobacco, E-cigarette), and/or cessation was not explicitly included in the assessment as an outcome. Previous literature has shown that quit intentions vary between smokeless tobacco users and combustible tobacco users [27]. In addition, the literature on the cessation experiences of electronic cigarettes versus combustible tobacco is still emerging, with some studies suggesting that while there is overlap, clear differences may exist [28]. Because of these reasons, this scoping review only evaluates evidence relating to combustible tobacco. The search strategy was not restricted by participant characteristics including age, sex, location or any pre-existing medical, behavioural or mental health diagnoses. Search strategy and study inclusion was not limited by year of publication or publication date. We did not predetermine a specific timeframe for cessation when screening studies. Rather, we judged based on the author's presentation of the dependent variable.

2.3 | Screening process and data extraction

All data screening was conducted using Covidence, a web-based software platform designed to support systematic and other literature reviews [29]. Four databases were searched for this review: PubMed, ERIC-APA-CINAHL, PsychINFO and EMBASE. An initial search was conducted 8 June 2022 and updated 6 August 2024. The electronic search strategy can be found in Table S1, Supporting Information. The PRISMA diagram shown in Figure 1 displays the article search and selection process. After duplicates were removed, data screening occurred in three stages. Title/abstract review and full-text review (stages 1 and 2, respectively) were completed by the first author and a trained graduate research assistant. In the instance of disagreement, consensus was met by the second author. Stage 3 (i.e., data extraction) was completed by the first and third authors according to the data collection spreadsheet for this scoping review (Table S2). The first author consolidated information across the two abstractors and condensed material in its final form. All authors reviewed the abstracted data to confirm accuracy, and issues were addressed via discussion and consensus. As this review aimed to describe the existing evidence related to our topic, the scientific level of evidence of included studies is not discussed, as is accepted practice for a scoping review [26, 30, 31].

2.4 | Model of executive functioning

There is no gold standard of what constitutes EF [32], however, there are three generally agreed-upon categories including self-regulation, working memory and cognitive flexibility [4]. For this study, EF skills were categorised based on a model reported by Adele Diamond [4]. EFs were categorised into three main groups: working memory, self-regulation and cognitive flexibility. Additionally, higher-level EF which are skills that rely on working memory, self-regulation and cognitive flexibility, are also considered. Working memory requires the ability to store information and manipulate it, for example, recalling a list of randomly presented words and repeating them in alphabetical order [5]. Working memory can further be categorised into verbal or visuo-spatial depending on the way that information is presented, either verbally or non-verbally, respectively [4]. Cognitive flexibility, also known as set-shifting or perspective shifting, is the ability to reimagine items in space, to consider things from another's perspective, or to alternate responses based on stimuli presented. For example, cognitive flexibility may be assessed by asking a participant to categorise a series of cards based on either colour, shape or number depending on the ongoing and changing feedback received throughout the task [33]. Self-regulation encompasses skills of inhibition, impulsivity, attention and emotional regulation. Diamond proposes that working memory, cognitive flexibility and self-regulation are all needed to adequately perform higher-level EF-focused tasks. Higher-level EFs are described as a set of skills including planning, reasoning and problem-solving. The definition of

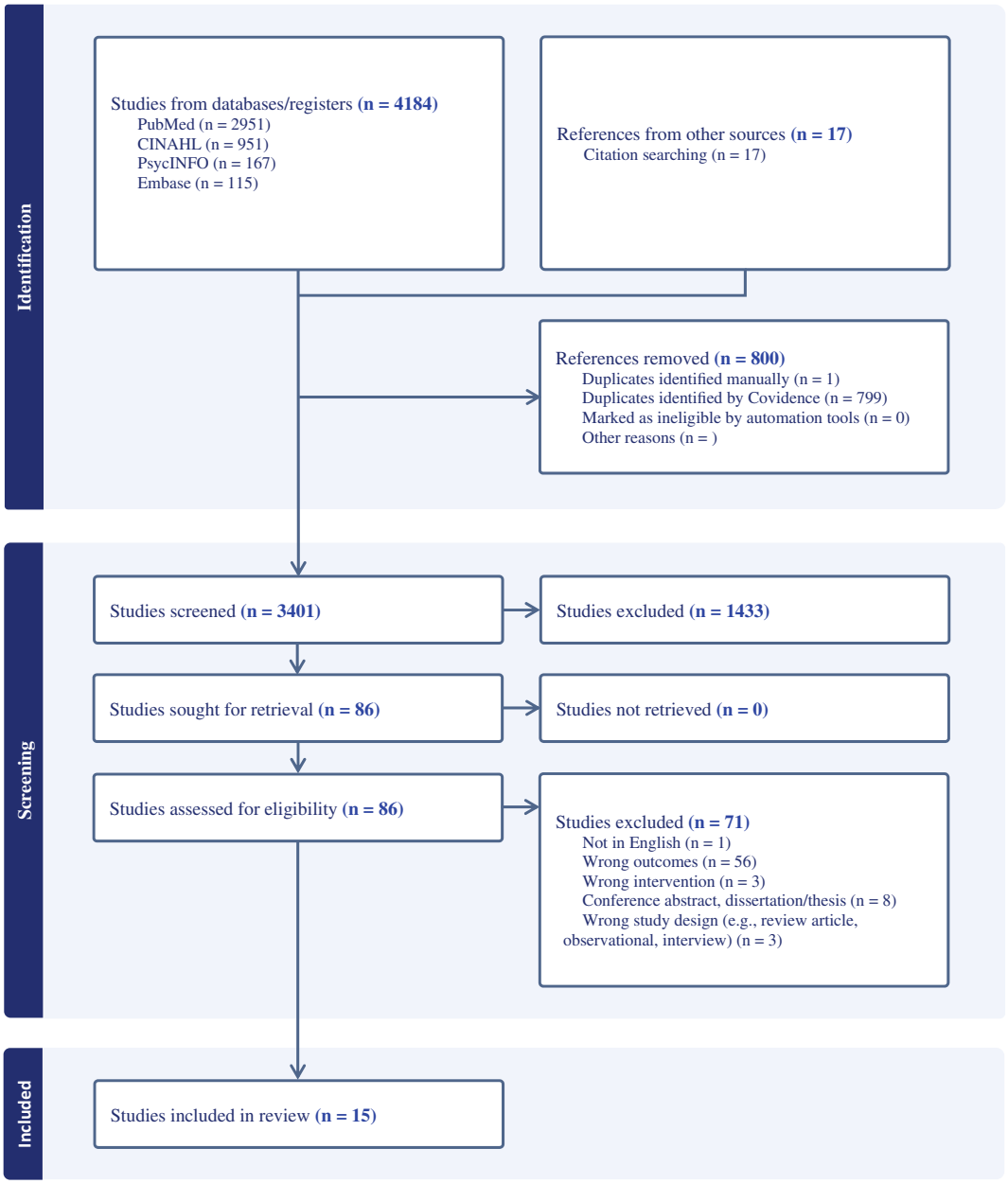

FIGURE 1 PRISMA-ScR diagram.

higher-level EF may be further extended to include decision-making based on the discussion of Diamond's model from Sohlberg et al. [5]. This extended model describes how decision-making may require a combination of EFs, or higher-level EFs from Diamond's model, and therefore was deemed relevant for inclusion during this screening process.

2.5 | Categorisation of executive function measures

Researchers categorised measures of EF based on the methods used by Domínguez-Salas et al. [34]. Categorisation was based on how the measures were originally presented by the authors of the study. Discrepancies in measure classification between studies were categorised based on the intention of the original publishing author of the measure itself.

3 | RESULTS

Across databases, the search yielded 4184 articles. An additional 17 articles were identified through citation hand-searching. The search in PubMed yielded 2951 articles. Comprehensive searches on ERIC-APA-CINAHL,

EMBASE and PSYCHINFO yielded 951, 115 and 167 articles, respectively. After 800 duplicates were removed, 2054 articles were imported for title/abstract screening. A total of 76 articles advanced for full-text screening. Following full article screening, 15 articles were included and extracted. Table 1 shows the study characteristics of the included studies and Table 2 details findings from each study as related to EF and smoking cessation.

3.1 | Study characteristics

The studies included in this review were published between 2004 [35] and 2024 [36]. A majority of the studies were conducted in the United States (73%, $n = 11$). Eight of the studies utilised a randomised control trial design. The remaining articles were non-randomised cross-sectional studies ($n = 3$), secondary analyses ($n = 2$) and cohort studies ($n = 2$). One study administered only pharmacotherapy as their intervention [37]. Four studies administered a combination of pharmacotherapy and psychological therapy [18, 35, 36, 38] and four studies administered only psychological intervention as treatment [39–42].

3.2 | Sample characteristics

Studies included an average of 245 participants, ranging from 30 to 1776. Studies recruited a variety of individuals of different ages, socio-economic strata and pre-existing mental health diagnoses. Within the smoking population, one study evaluated cessation patterns in low socio-economic groups [43] and four studies evaluated cessation patterns in individuals with mental health diagnoses [18, 35–37]. A wide range of age groups were included across studies including adolescents, young adults and adults. For the 12 studies that reported a mean age of participants, the overall mean age of participants was 35 years old. Across participants from all 15 studies, 53% were female.

3.3 | Executive function outcomes

3.3.1 | Working memory

Five studies included in this review utilised measures of working memory [18, 35–37, 43]. Measures included

TABLE 1 Characteristics of included studies.

Authors	Year	*N*	Female n (%)	Mean age[a]	Country	Study design	Executive function(s) assessed
Dolan et al.	2004	72	39 (54)	45.83	US	RCT	WM, CF, inhibition, ATTN
Rukstalis et al.	2005	454	244 (54)	46.20	US	RCT	Impulsivity
Krishnan-Sarin et al.	2007	30	16 (53)	N/A	US	Cross-sectional	Impulsivity, ATTN
Culhane et al.	2008	114	36 (32)	N/A	US	RCT	WM, inhibition, ATTN
Moss et al.	2009	31	8 (26)	40.10	US	RCT	WM, CF, ATTN, DM
Muraven et al.	2010	122	58 (48)	N/A	US	RCT	Inhibition
Powell et al.	2010	141	76 (54)	33.20	US	RCT	Impulsivity, inhibition, ATTN
Sheffer et al.	2012	97	57 (59)	48.16	US	Cross-sectional	WM, impulsivity, inhibition, reasoning
Kvaavik and Rise	2012	1776	1034 (58)	25.25	Norway	Cohort	Impulsivity
Wegmann et al.	2012	139	68 (49)	14.80	Germany	Cross-sectional.	Impulsivity
Ochsner et al.	2014	106	29 (27)	40.67	Switzerland	RCT	Planning
Morean et al.	2015	64	34 (53)	16.36	US	Secondary Analysis	Impulsivity
Weckler et al.	2017	141	56 (40)	16.27	US and Netherlands	Secondary Analysis	Impulsivity
Fox et al.	2017	255	110 (43)	45.8	US	RCT	Inhibition, CF
Flaudias et al.	2024	130	72 (55)	47.47	France	Cohort	Inhibition, WM, CF, DM

Abbreviations: ATTN, attention; CF, cognitive flexibility; DM, decision-making; HLEF, higher-level executive functioning; RCT, randomised control trial; WM, working memory.

[a]Mean age was not presented by three studies.

TABLE 2 Summary of findings for included studies ($N = 15$).

Executive function	Assessment	Author	Finding[a]
Working memory	Visuo-Spatial Working Memory Test	Dolan et al.	−
		Moss et al.	−
	MicroCog	Sheffer et al.	−
	Digit Span	Culhane et al.	−
	WAIS-III	Moss et al.	+
	CVLT	Culhane et al.	−
		Moss et al.	−
	Spatial n-back	Flaudias et al.	−
Cognitive flexibility	Trail Making Tasks	Moss et al.	+
		Flaudias et al.	−
		Fox et al.	−
	WCST	Moss et al.	−
		Dolan et al.	+
	Verbal Fluency Task	Flaudias et al.	−
	COWAT-FAS	Fox et al.	−
Self-regulation			
Impulsivity	BIS-11	Weckler et al.	+
		Sheffer et al.	+
		Krishnan-Sarin et al.	−
		Kvaavik and Rise	−
		Morean et al.	+
	Discounting tasks	Weckler et al.	−
		Krishnan-Sarin et al.	+
		Sheffer et al.	+
	BART	Sheffer et al.	−
	Eysenck Impulsiveness Scale	Sheffer et al.	−
		Powell et al.	−
		Wegmann et al.	+
	Current Symptoms Scale	Rukstalis et al.	+
	The Sensation Seeking Scale	Powell et al.	−
	Tridimensional. Personality Questionnaire	Powell et al.	−
Inhibition	Iterative Voice Response	Muraven et al.	+
	Go/No-Go Task	Sheffer et al.	−
	Stroop Test	Dolan et al.	−
		Culhane et al.	+
		Flaudias et al.	−
		Fox et al.	−
	FrSBe	Sheffer et al.	−
	Fukushima et al.'s antisaccade task	Powell et al.	+
	Hayling Test	Flaudias et al.	−
Attention/CPT	Dougherty et al.'s CPT	Powell et al.	+
	CPT-II	Moss et al.	−
		Krishnan-Sarin et al.	+
		Dolan et al.	−
	CPT-AXE	Culhane et al.	+

(Continues)

TABLE 2 (Continued)

Executive function	Assessment	Author	Finding[a]
Higher-level executive functioning			
Decision-making	IGT	Moss et al.	–
		Flaudias et al.	–
Planning	Action Planning	Ochsner et al.	–
	Coping Planning	Ochsner et al.	+
Reasoning	MicroCog-Reasoning	Sheffer et al.	–

Abbreviations: BART, Balloon Analogue Risk Task; BIS-11, Barratt Impulsiveness Scale Version 11; COWAT-FAS, Controlled Oral Word Association Test; CPT, Continuous Performance Test; CVLT, California Verbal. Learning Test; FrSBe, Frontal. Systems Behaviour Scale; IGT, Iowa Gambling Test; MicroCog, MicroCog Assessment of Cognitive functioning; TMT-B, Trail Making Test Part B; WAIS-III, Wechsler Adult Intelligence Scale-III Digit Span Subtest; WCST, Wisconsin Cart Sorting Test.

[a]Findings indicate the statistically significant/insignificant relationship between performance on the specified assessment and smoking cessation outcomes and are represented through (+) and (−) symbols respectively.

a computerised visuospatial working memory task [35, 37, 44, 45], an unspecified digit-span task [18], the digit-span subtest from the Wechsler Adult Intelligence Scale (WAIS-III) [37, 46], the MicroCog Assessment of Cognitive Functioning (MicroCog) [43, 47] and the spatial n-back test [48]. The MicroCog is a test of both visuospatial and verbal working memory and the digit-span tasks are measures of only verbal working memory. Four of five studies reported a null relationship between working memory and smoking cessation success. Only one study examining working memory found performance on the digit span subtest of the WAIS-III significantly predicted cessation outcomes. Specifically, individuals who did not stop smoking had significantly poorer performance on backward digit span recall ($p = 0.04$), a task where one must restate numbers presented verbally in reverse order [37]. Overall, findings from this review regarding the relationship between working memory and smoking cessation is limited. The studies included in this review tentatively suggest that working memory is not related to smoking cessation outcomes, though further work is needed to make definitive claims in this area.

3.3.2 | Cognitive flexibility

Four of the 15 studies included in this review evaluated cognitive flexibility and reported a significant relationship with smoking cessation outcomes [35, 37]. Two studies utilised the Wisconsin Card Sorting Test (WCST) [33] and three studies utilised trail making tests [49]. Two of three studies reported insignificant findings relating performance on trail making tasks to smoking cessation outcomes. However, Moss et al. [37] reported that individuals who did not successfully stop smoking had significantly worse performance on the TMT-B compared to those who did quit successfully ($p = 0.02$), indicating a poorer ability to mentally switch between opposing cognitive stimuli [37]. Dissimilar results were found when examining the relationship of smoking cessation to cognitive flexibility using the WCST. Moss et al. [37] found no significant differences in performance on the WCST between individuals with TUDs and individuals without TUDs diagnosed with schizophrenia. In contrast, Dolan et al. [35] found that for individuals diagnosed with schizophrenia, successful cessation was predicted by better cognitive flexibility. Namely, a significantly lower percentage of total errors ($p = 0.04$), non-perseverative errors ($p = 0.04$), a higher number of categories completed ($p = 0.05$) and a significantly lower number of trials to complete the first category ($p = 0.02$). However, for a control population without a schizophrenia diagnosis, Dolan et al. found that there was not a significant difference in WCST performance between individuals with TUDs and individuals without TUDs. Similarly, performances on a verbal fluency task and the Controlled Oral Word Association Test (COWAT-FAS) were not significantly related to smoking cessation outcomes. Given the limited and diverging evidence, there is insufficient data regarding how cognitive flexibility relates to smoking cessation.

3.3.3 | Self-regulation

Self-regulation was the most frequently assessed area of EF and was included in 14 of 15 studies included in this review. Guided by Diamond's model, we present results in three sub-categories: impulsivity, inhibition and attention [4].

Impulsivity

Eight (53.3%) of the studies included in this scoping review assessed participant impulsivity and its relationship

to cessation success [38–43, 50, 51]. Of those studies, a majority assessed impulsivity through self-report measures including the Barratt Impulsiveness Scale Version 11 (BIS-11) ($n = 5$) [52], Eysenck Impulsiveness Scale ($n = 3$) [53–57], Current Symptoms Scale ($n = 1$) [38], Sensation Seeking Scale ($n = 1$) [50] and the Tridimensional Personality Questionnaire ($n = 1$) [50]. Additional measures of impulsivity used to assess the relationship between impulsivity and smoking cessation were the Balloon Analogue Risk Task (BART) [58] and Connors' Continuous Performance Test (CPT-II) [59]. While Krishnan-Sarin et al. [41] reported the CPT-II as a measure of impulsivity, the authors of this scoping review will discuss these results, along with rationale and results for all continuous performance tests (CPT), in the attention section.

Six of eight studies reported a significant relationship between performance on measures of impulsivity and cessation outcomes [38–43]. In three out of five studies that used the BIS-11, there was a null relationship between impulsivity and cessation outcomes. However, two of five studies found that adolescents who were highly impulsive on the BIS-11 were significantly more likely to stop smoking if they received contingency management or cognitive bias modification treatments [39, 40]. One of three studies found that higher impulsivity as measured by the Eysenck Impulsiveness Scale was significantly related to lower levels of abstinence [42]. Rukstalis et al. found that individuals who reported increasing levels of impulsivity symptoms during the first week of a cessation attempt were half as likely to achieve abstinence compared to those who did not report an increase in symptoms [38]. Finally, the BART, Sensation Seeking Scale and the Novelty Seeking Scale of the Tridimensional Personality Questionnaire did not find a significant relationship between impulsivity and smoking cessation outcomes [43, 50].

Inhibition

Inhibition was the second most commonly assessed area of self-regulation in studies included in this review (46.7%, $n = 7$) [18, 35, 36, 43, 50, 60, 61]. Across these studies, six different measures of inhibition were used. The only repeated measurement was the Stroop Test, utilised by four of seven studies [18, 35, 36, 61]. The remaining five assessments were used in one study each and included the Go/No-Go Task [43], self-report using iterative voice response [60], the Frontal Systems Behaviour Scale [43, 62], Fukushima et al.'s anti-saccade task [50, 63], Dougherty et al.'s CPT [50, 64] and the Hayling Test [65]. While Doughterty's CPT was introduced as a measure of impulsivity, it will be discussed below in the attention section along with our rationale for this decision.

Inhibition was related to smoking cessation outcomes at levels of statistical significance in three of seven studies [18, 50, 60]. Overall, individuals who practiced self-control, even if it was not related to smoking, and those with faster responses on the Stroop inference test were more likely to be abstinent from smoking at study conclusion. Additionally, poorer inhibition on the Oculomotor Response Inhibition task predicted failure to maintain 7-day abstinence [50].

Attention

Attention was significantly related to smoking cessation outcomes in three of five studies included in this review [18, 41, 50]. Across all five studies, domains of attention were evaluated through three different CPTs: CPT-II [35, 37, 41, 59, 66], CPT-AXE [18] and Dougherty's CPT [50, 64]. Depending on authors, CPTs were described as measures of impulsivity, inhibition or attention. In some instances, the same CPT was used by multiple studies but presented by one group as a measure of impulsivity and by another as a measure of attention [35, 37, 41]. To allow for clearer comparison across studies and different CPT measures used, we chose to categorise CPTs as measures of attention, based on Rosvold et al.'s intent for the first CPT created in 1956 as a measure of sustained attention [67], though we stated in the above sections how authors originally categorised the assessments.

To classify areas of attentional deficit, CPTs may measure and report reaction time, % hit rate, % omissions (i.e., missed stimuli), % commissions (i.e., falsely responding to non-stimuli), reaction time response variability and attentional index [37]. Across the three different CPTs used, three studies reported reaction time [18, 35, 41], while % omission [35, 41], % commission [35, 41], % hit rate [35, 37], hit reaction time variability [18, 35] and attentional index [35, 37] were only reported in two studies each. Most attentional domains examined across studies and different versions of CPT measures were not found to be significantly related to smoking cessation outcomes. However % commission rate on CPT-II ($p < 0.05$), Dougherty's CPT ($p = 0.03$), and hit reaction time on CPT-AXE ($p = 0.003$) were each significantly related to smoking cessation outcomes [18, 41, 50]. These findings indicate that individuals who responded in error or very quickly were more likely to fail in their cessation attempts.

3.3.4 | Higher-level executive functions

Higher-level EFs included reasoning, planning, problem-solving and decision-making and were incorporated as outcome measures in four studies included in this scoping review [36, 37, 43, 68]. Assessments included item

responses to assess planning domains [68], the Iowa Gambling Test [69] and the MicroCog [43, 47]. None of the three studies measuring decision-making reported a significant relationship between performance on the Iowa Gambling Test and smoking cessation outcomes. Only one study examined reasoning and reported similar findings. Results related to planning were divergent. Ochsner et al. [68] reported that high coping planning skills were significantly related to sustained abstinence, however, only in the presence of high social support. The authors found that in the absence of high social support, high coping planning skills were not significantly related to smoking cessation outcomes. The authors reported similar findings for action planning, stating that there was an insignificant relationship between action planning and sustained abstinence regardless of the level of social support received.

3.4 | Smoking cessation outcomes

An overview of cessation definitions utilised by each study is provided in Table 3. We report on the smoking cessation biochemical confirmation parameters and methods reported in the 15 studies included in this review. Seven of 15 studies measured cessation through 7-day point prevalence. Twelve of 15 verified cessation through biochemical confirmation with a majority ($n = 8$) utilising carbon monoxide (CO) expired breath at a single point. Notably, one cohort study measured cessation by asking individuals to report their current smoking status after a 6-year period [51]. All but three studies included in this review used biochemical verification of smoking cessation for at least one study outcome point. We discuss the implications of variable measures of smoking cessation on EF below.

4 | DISCUSSION

This scoping review includes studies that evaluated the relationship between EFs and cessation success to identify and map the extant literature in hopes of guiding future research. If researchers should consider adapting evidence-based cessation programming to account for EF difficulties, they must understand any potential gaps in

TABLE 3 Smoking cessation biochemical confirmation parameters and methods in included studies.

Authors	Cessation measurement	Biochemically confirmed?[a]	Biochemical confirmation methods and parameters
Dolan et al.	7-day point prevalence	+	CO <10 ppm; plasma cotinine level <15 ng/mL[b]
Rukstalis et al.	7-day point prevalence	+	CO <10 ppm
Krishnan-Sarin et al.	7- and 30-day point prevalence	+	CO <8 ppm; urine cotinine levels <50 ng/mL
Culhane et al.	4-week continuous abstinence	+	CO <9 ppm
Moss et al.	7-day point prevalence	+	CO < 10 ppm
Muraven et al.	Repeated point prevalence (3, 10, 19 and 28 days)	+	CO ≤10 ppm
Powell et al.	7- and 30-day point prevalence; 3-month continuous abstinence	+	Salivary cotinine levels <20 ng/mL
Sheffer et al.	Repeated point prevalence (1, 2, 3, 4, 8, 12 and 28 weeks)	+	CO ≤8 ppm
Kvaavik and Rise	6-year point prevalence	–	
Wegmann et al.	3-week point prevalence	–	
Ochsner et al.	Continuous abstinence (average of 29 days) and point prevalence	+	CO ≤9 ppm
Morean et al.	7-day point prevalence	+	Urine cotinine levels ≤50 ng/mL
Weckler et al.	7-day point prevalence	–	
Fox et al.	7-day point prevalence	+	Cotinine levels (value/type unspecified)
Flaudias et al.	Repeated point prevalence (1, 3 and 6 months)	+	CO < 10 ppm

[a]Findings indicate the use of biochemical confirmation of smoking cessation with the use of a + sign while the absence of biochemical confirmation of smoking cessation is denoted with a – sign.
[b]Verification using plasma cotinine levels was used for an unspecified number of participants, not all.

the current base of knowledge. To guide the selection process, researchers chose Adele Diamond's model of EF [4]. This model identifies three primary domains of EF including working memory, cognitive flexibility and self-regulation, as well as higher-level EFs. Across all 15 studies, all areas included in Diamond's model of EF were assessed.

A primary goal of this scoping review was to identify how EF has been studied previously as related to smoking cessation. This scoping review illustrates that gaps remain in the both the breadth (i.e., the number of studies) and depth (i.e., the content of the studies) of the existing literature. Only 15 studies met inclusion criteria for clearly evaluating the role of EF in smoking cessation. When considering the methodology of the studies, there is notable variability in the EFs assessed and in the participants themselves (e.g., age, presence of pre-existing mental health conditions). The variability across studies precluded a systematic review or meta-analysis that would have allowed for much needed examination on how EFs relate to smoking cessation for different groups of people. There is a need for research on targeted areas of EF using common assessment measures. Specifically, there is limited data evaluating how cognitive flexibility, working memory and higher-level EFs relate to smoking cessation.

In this review, four included studies evaluated the role of cognitive flexibility in smoking cessation. Two of the four studies found a significant link between cognitive flexibility and smoking cessation. However, given the diverging findings and small number of studies, overall conclusions are inconclusive. As it relates to smoking cessation, cognitive flexibility involves changing how individuals think about things, for example considering multiple ways to solve a problem. This may be especially important for individuals with TUDs who have made multiple cessation attempts. Having strong cognitive flexibility skills might allow a person to examine previous cessation attempts and identify what went wrong and then formulate a new plan to try in a different way. Cognitive flexibility may also play an important role in aiding those who return to use from the same triggers or events. For example, if someone always smokes after a meal, someone with good cognitive flexibility may recognise this pattern and instead take a walk or call a friend after meals.

A hypothesis underlying this scoping review was that since working memory and higher-level EFs, such as decision-making, reasoning and planning, are important to problem-solving and goal attainment [4, 5], they may also be necessary for smoking cessation. Findings regarding higher-level EFs were also contrary to researchers' expectations given previous research that has reported higher-level EFs are significantly related to treatment outcomes in individuals with alcohol, stimulant and opioid use disorders [70]. In this review, findings did not report a significant relationship between performance on measures of decision-making and reasoning and smoking cessation outcomes. Findings related to performance on planning measures were inconclusive as it relates to smoking cessation outcomes. Overall, studies examining differing areas of higher-level EFs were limited and findings may be deemed inconclusive. While one study found that poorer working memory was related to worse cessation outcomes [37], this result must be interpreted with caution. This study used digit span recall and though it is widely used as a measure of working memory, Diamond argues that this task may not fully capture working memory skills because those with photographic memories may be able to visualise numbers and simply read the list rather than mentally retain and recall the information [4]. Future studies should include measures of working memory and higher-level EFs to help clarify the possible relationship between these factors and smoking cessation outcomes.

A notable observation from this review was the lack of consistency in EF measures across studies. A total of 30 different assessments were used to evaluate EFs across all 15 studies. Even in the case where studies used the same measure, authors occasionally categorised them as measuring different EFs (e.g., CPT-II was classified as a measure of both attention and impulsivity). Because of the wide variability in areas assessed and inconsistency of measure classification, researchers are unable to make any conclusive statements about the role of EF in smoking cessation. A common set of outcome measures should be established that will allow for better comparison across studies. One option worth consideration is the NIH-Toolbox. The NIH Toolbox offers measures of cognition, emotional, motor and sensory domains across the lifespan in both English and Spanish. Measures included in the NIH Toolbox have been validated through rigorous qualitative and quantitative testing and are suitable for individuals with a wide range of disorders and 'sociodemographically diverse clinical populations' [71, p. 317]. Another option is the Behaviour Rating Inventory of Executive Function which is an ecologically valid self-report questionnaire available in both adolescent and adult versions that provides an overall global composite of EF [72, 73]. By establishing a common set of outcome measures to evaluate EF in persons who are attempting to quit smoking, researchers could better understand how EF impairs cessation efforts and inform future cessation protocols to support needs based on age, socioeconomic status, and pre-existing neurologic or mental health conditions.

Across studies, the definition of 'cessation' was highly variable, both in the term used and the length of time used to qualify successful cessation. This is demonstrated by differences in measures of cessation either through 7- or 30-day point prevalence, or measures of continuous abstinence that evaluate cessation several months beyond the quit date. It is unclear how these varying timelines may accurately predict smoking cessation amongst individuals with impaired EF. Seven-day point prevalence was the most commonly used measure of cessation. However, this does not necessarily take into account the different phases of cessation that may prove difficult for individuals with impaired EF [74]. It would be important, especially with EF dysregulation, to follow people over time to see the impact of EF as they work to establish and maintain cessation. While some studies assess cessation at multiple timepoints, this standard was not reflected for studies included in this review.

Another notable finding in this review was the lack of literature published between 2018 and 2023. This presents as a unique lapse in publication focusing on cessation of combustible tobacco. We speculate that this may be caused by a shift in focus of the literature based on observations and a noted decrease in publications on PubMed using the search term 'smoking cessation' beginning in the year 2017. Of the 4184 articles reviewed for inclusion in this review, 14 were published from 2018 to 2023. These were excluded because they did not evaluate EF ($n = 9$), were not related to cessation ($n = 3$) or were not peer-reviewed literature ($n = 2$). We noted in the articles centred on cessation that researchers were interested in evaluating how factors such as self-efficacy, coping, smoking urges, depression and anxiety related to cessation outcomes. However, we noted a distinct lack of inclusion of EF during this timeframe. These shifts may be due to funding priorities or other societal shifts in research and policy-making.

Future work would benefit from utilising the updated guidelines on defining and measuring smoking abstinence from the Society for Research on Nicotine and Tobacco Treatment Research Network [75]. The updated guidelines recommend reporting: (i) the abstinence product definition (i.e., abstinence from all combustible tobacco products, abstinence from combustible and smokeless tobacco products, or abstinence from combustible, smokeless and alternative tobacco products); (ii) abstinence outcome measures that reflect both point-prevalence and continuous abstinence; and (iii) abstinence duration reported at multiple timepoints (i.e., end of treatment, 3 and 6 months) [75]. Accounting for these standards in future research is necessary to fully evaluate the implications of EF impairment on lifetime smoking cessation success.

Articles included in this scoping review also included a variety of outside treatments across studies (i.e., pharmacology, psychotherapy). It is impossible to know whether success in cessation was solely linked to EF skills or due to these interventions. To help clarify, future work evaluating the role of EF and cessation should consider accounting for these confounds in their analyses. Alternatively, future cessation research could run moderation analyses by component to see if cessation success by intervention type is different by EF skills. In addition, future work may continue to consider how EF training programs such as Inhibitory Control Training [76] and Goal Management Training [77] may impact EFs to support smoking cessation attempts. While not a primary aim of the current review, such training programs may be beneficial to shed light on how EFs interact with processes needed to achieve smoking cessation success. Researchers pursuing this work may consider addressing EFs by considering methods from cognitive rehabilitation programs by implementing compensatory strategy training and integration of adaptive methods that support EFs [78].

4.1 | Limitations

This study had a number of limitations that should be addressed in future work. While a critical quality appraisal of prior studies would be beneficial, the heterogeneity in use of EF terms, definitions of smoking abstinence, and variability in assessment measures across studies made the possibility of conducting such an appraisal inappropriate. It is possible that the search criteria were limited in its scope, resulting in under identification of relevant articles. Likewise, it is possible that the definition of EF chosen for this review likewise limited its overall scope. While this review used the definition of EF established by Adele Diamond [4], definitions for EF may vary and there are articles that were excluded based on this choice of EF framework. Additionally, as demonstrated in this review, researchers often use the same measures but categorise them differently. We chose to categorise measures of CPT in the attention category based on the intentions of the test creators. However, it is noted that the CPT contains test that may be categorised into different areas including impulsivity and inhibition. Because of the limited number of overall studies and the heterogeneity among them, we chose to categorise the entire test into an attention category. Thus, we were unable to compare findings across different areas of EF. Future studies may consider parsing out subsections of the CPT to determine how findings compare to other measures of

impulsivity and inhibition. Finally, the heterogeneity in the included studies limits researchers' ability to make substantive conclusions to guide clinical strategies for targeting EF in smoking cessation treatments. Nonetheless, this review identifies clear gaps in our current body of knowledge and offers directions for future research to address these limitations.

5 | CONCLUSION

Understanding how EF might impact successful tobacco cessation has important implications for the general smoking population but also for tobacco users with pre-existing EF deficits. While few studies have examined the relationship between EF and cessation success, those included in this scoping review indicate that there is rationale for incorporating EF-focused cognitive rehabilitation techniques into already established evidence-based smoking cessation programs to help address barriers to cessation success. To move research and clinical practice forward, this review identified a clear need to continue evaluating EF in persons trying to quit smoking using a set of common measures. Particular consideration should be given to higher-level EFs including reasoning, planning, problem-solving and decision-making. Action to address these gaps will help identify ways to direct limited resources that may be used to support persons in their cessation attempts and improve cessation outcomes.

AUTHOR CONTRIBUTIONS

Each author certifies that their contribution to this work meets the standards of the International Committee of Medical Journal Editors.

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CONFLICT OF INTEREST STATEMENT

The authors do not have any financial or non-financial conflicts of interest to report.

DATA AVAILABILITY STATEMENT

Data will be made available upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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