EXECUTIVE FUNCTIONING AND EMOTION REGULATION IN CHILDREN WITH AUTISM SPECTRUM DISORDER: UNDERSTANDING HETEROGENEITY IN PRESENTATION AND INTERVENTIONS

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Abstract

Autism spectrum disorder (ASD) is a complex neurodevelopmental disorder characterized by social communication deficits and restricted patterns of behaviours and interest. Children with ASD present with a wide range of neurocognitive abilities, including challenges in emotion regulation (ER: ability to identify and modulate one's own emotional response to situations) and executive functions (EF: cognitive processes involved in self-regulation, goal-directed behaviours, and higher order thinking). Given that ER and EF skills are essential in everyday functioning, gaining a better understanding of the presentation of these cognitive processes in children with ASD and how they can be targeted in interventions could have important implications. The current manuscript aimed to: (1) understand the broad presentation of everyday EF and ER skills in children with ASD by using a person-centered approach analysis (Study 1), and (2) examine the evidence and existing support for targeted interventions in these areas by conducting a systematic review of the literature (Study 2). Results from Study 1 indicated that individuals with ASD present with heterogeneous EF and ER abilities, ranging from impaired to developing as expected, as assessed through an informant-based measure. The latent profile analyses revealed three profiles: *broadly affected*, *narrowly affected,* and *intact* EF and ER skills, demonstrating that being on the autism spectrum is not sufficient to infer challenges in EF or ER. Results from Study 2 identified 22 studies assessing interventions targeting ER and/or EF skills in children with ASD. Three types of interventions were identified as showing promising results: (1) cognitive behavioural interventions targeting ER specifically, (2) mindfulness-based interventions, and (3) group-based martial arts interventions. However, more research is required before these are considered evidence-based practices. Additionally, most interventions were assessed on a narrow range of children with ASD, primarily school-age

males with no significant cognitive delays, thus limiting the generalizability of results across the entire autism spectrum. Taking a person-centered approach when working with this population is extremely important. It is hoped that information from this manuscript can be used to inform future research in EF and ER in ASD and the development of targeted intervention programs specific to this clinical group.

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Chapter 1: General Introduction

Autism spectrum disorder (ASD) is a complex neurodevelopmental disorder in which individuals present with difficulties in social communication and interaction, and have restricted, repetitive patterns of behaviours and interests (American Psychiatric Association [APA], 2013). These challenges persist well into adulthood, having lasting impacts on personal, social, and occupational functioning (Chiang & Wineman, 2014; de Vries & Geurts, 2015, Kuhlthau et al., 2010; Smith et al., 2019). Core symptoms can range from mild to profound, and individuals with ASD often present with a broad range of co-morbid medical and psychological disorders (Amaral et al., 2008; Lai et al., 2014; Simonoff et al., 2008), contributing to the heterogenous clinical presentation of these individuals (Masi et al., 2017).

To add to the complexity of ASD presentation, individuals with autism also present with a wide range of neurocognitive and language skills, and with challenges in various aspects of cognitive, behavioural, and emotional regulation (e.g., Jahromi et al., 2013; Loveland, 2005; Mazefsky et al., 2013, 2014). Challenges in regulation, especially emotion regulation (i.e., the ability to identify and modulate one's own emotional response to situations), and in discrete processes involved in regulation, such as executive functions (i.e., top-down cognitive processes involved in self-regulation, goal-directed behaviours, and higher order thinking) have been postulated to play a significant role in ASD symptomology and clinical presentation (e.g., de Vries & Geurts, 2012; Gilotty et al., 2002; Hill, 2004; Jahromi et al., 2013; Kenworthy et al., 2009; Samson et al., 2014; Van Eylen et al., 2015; Yerys et al., 2019). More specifically, executive and regulation deficits in children with ASD have been thought to be associated with the higher rate of co-morbid internalizing and externalizing disorders seen in this population (e.g., Baez et al., 2020; Hollocks et al., 2014; Mazefsky et al., 2013; Sullivan et al., 2019), while

also contributing to challenges in social, adaptive, and academic development (e.g., Berkovits et al., 2017; Jahromi et al., 2013; Pellicano et al., 2017; Pugliese et al., 2015). In addition, treatment outcome of children with ASD has also been shown to be influenced by emotion regulation and executive functioning skills (e.g., Bishop-Fitzpatrick et al., 2016; Friedman & Sterling, 2019; Gardiner & Iarocci, 2018; Pellicano et al., 2017; Pugliese et al., 2016; Tajik-Parvinchi et al., 2020). Therefore, gaining a better understanding of these processes and their interactions within this neurodiverse population could help better support the development and overall functioning of children with ASD.

The current manuscript attempts to shed some light on regulation challenges in children with ASD by focusing primarily on top-down cognitive processes involved in regulation. Given how broad the construct of regulation is, the current manuscript takes a focused approached to regulation and explores specific processes, mainly core executive functions and emotion regulation. The first chapter of this manuscript provides the framework and the definitions of these constructs, while also explaining in more depth how they may contribute to ASD symptoms and presentation. The following two chapters (Chapter 2 and Chapter 3) contain studies that build on each other by first gaining a better understanding of the presentation of these regulation processes in children with ASD and by then exploring how they have been targeted in interventions for this population. More specifically, in the second chapter, a person-centered approach is used to determine the presence of profiles in children with ASD based on parental report of everyday executive functioning and emotion regulation skills. The third chapter comprises a systematic review that explores the evidence and support for existing training programs and interventions aimed at improving specific aspects of regulation in children with ASD. Lastly, the results of both studies are brought together in a final chapter to discuss the

clinical implication of these findings and how they may be used to better support the development of targeted interventions for children with autism.

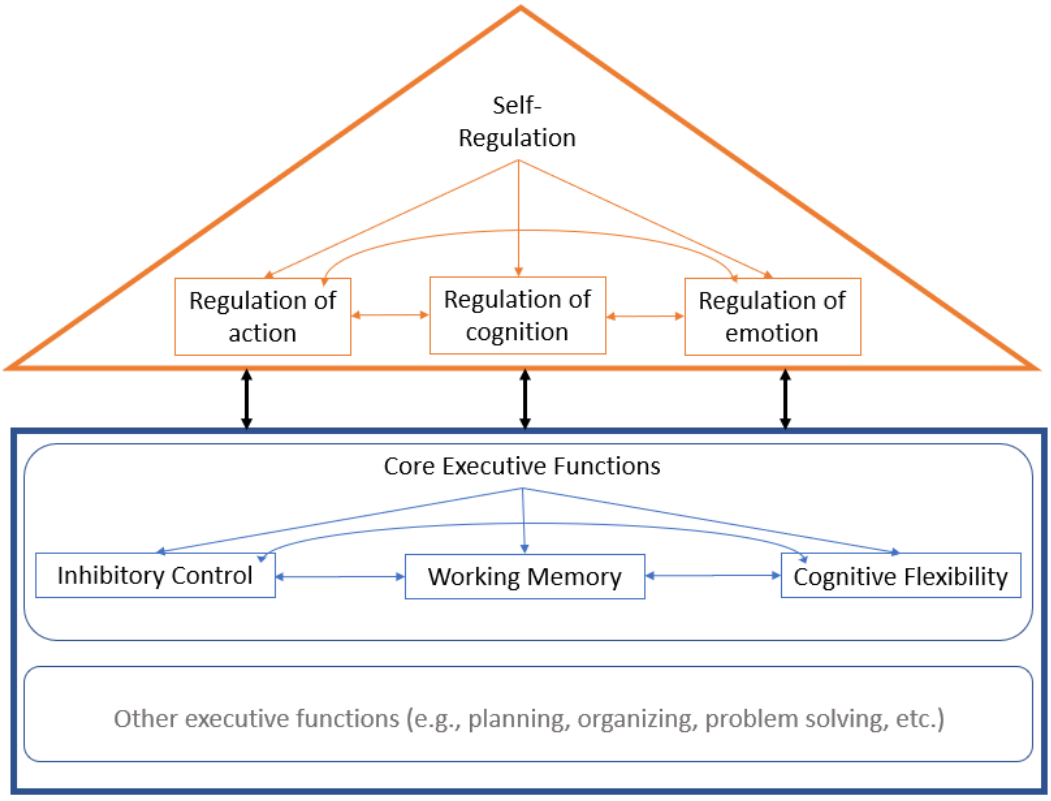
Framework of the Current Manuscript

Regulation and executive functioning are very broad constructs that have been studied extensively across many fields of research (e.g., cognition, personality, social, development, neuroscience, and clinical psychology). Although these fields bring in different perspectives, the diversity has also led to differing definitions and conceptualizations of regulation and executive functioning (e.g., Blair & Ursache, 2011; Eisenberg & Zhou, 2016; Goldstein et al., 2014; McCloskey & Perkins, 2012; Nigg, 2017). Over the years, several researchers have attempted to develop a unified framework for regulation and related processes such as executive functions (e.g., Blair & Ursache, 2011; Eisenberg & Zhou, 2016; Nigg, 2017). The conceptual framework for this manuscript is primarily based on Nigg's integrative conceptual framework of intrinsic aspects of regulation (i.e., self-regulation) (Nigg, 2017), while paying specific attention to Miyake's tripartite model of executive functioning (Miyake et al., 2000) (see Figure 1).

In the current manuscript *self-regulation* is seen as a broad, domain-general construct encompassing the ability to monitor and regulate one's own thoughts, emotions, and behaviours to effectively pursue a goal (Blair & Diamond, 2008; Kopp, 1982; Nigg, 2017; Shapiro et al., 2015; Zelazo & Lyons, 2012). Put simply, it is the intrinsic ability to have control over one's own actions and responses, including cognition and emotion. Previous researchers have at times equated self-regulation to emotion regulation. However, in this manuscript, emotion regulation is seen as a component within the bigger construct of self-regulation and is seen as interacting closely with processes involved in behavioural and cognitive regulation. Chapters 2 and 3 include measures of emotion regulation and therefore, a more thorough definition of this

construct is warranted. In the current manuscript, e*motion regulation*, also referred to as emotional control, is the ability to monitor and modulate the intensity, duration, and expression of one's emotions in order to interact with one's environment in an adaptive and socially appropriate manner (Cole et al., 1994; Eisenberg & Spinrad, 2004; Thompson, 1994). Emotion regulation is viewed as a complex and dynamic process that requires (a) adequate identification of emotions and arousal state in oneself; (b) engagement of appropriate self-soothing strategies when needed; and (c) the inhibition of maladaptive behavior in response to one's emotions (Cole et al., 2004; Gratz & Roemer, 2004; Gross, 2015; Southam-Gerow & Kendall, 2002).

Figure 1. Framework of Current Study



Note. Illustration of the interaction between self-regulation and its components (orange) and executive functioning processes (blue).

Although it is important to mention that many multilevel processes and elements can influence self-regulation, such as environmental (e.g., co-regulation with caregivers; Cibralic et al., 2019), psychological (e.g., presence of psychological disorders: Espy et al., 2011), and biological factors (e.g., child's temperament; Rothbart, 2011), the current framework focuses primarily on core executive functions and their connection to self-regulation, especially emotion regulation. *Executive functioning* (EF) is a broad umbrella term used to describe a wide range of cognitive skills involved in self-regulation, goal-directed behaviours, and higher order thinking (Denckla, 1996; Goldstein et al, 2014; Meltzer, 2018; Miyake et al., 2000). These include top-down mental processes such as inhibition, working memory, cognitive flexibility, planning, and many more. Executive functions are essential for everyday functioning as they are required to make and carry out plans, problem solve, adapt to new situations, and even to engage in socially appropriate behaviour (e.g., Diamond, 2013; Goldstein et al., 2014; Hughes, 2011). In the current framework, EF is viewed as distinct from self-regulation, with the understanding that executive functions are critical for the development of emotion, behavioural, and cognitive regulation (see Figure 1) (e.g., Nigg, 2017; Zelazo & Cunningham, 2007). Executive functions can play a role in domains outside of self-regulation, such as developing academic skills (e.g., Alloway & Alloway, 2010; Blair & Razza, 2007; Bull et al., 2008; Espy et al., 2004; Gathercole et al., 2003; Liew, 2012; St Clair-Thompson & Gathercole, 2006), and thus, are viewed as a separate construct from regulation (view Figure 1). However, there is a great deal of overlap between EF and self-regulation, especially when the specific goal is to regulate one's own behaviour or emotion to achieve a desired outcome. Then, in these situations EF skills are employed for self-regulation and are almost analogous (Nigg, 2017). Additionally, the close relationship between EF and self-regulation can also be describe as a feedback loop between these two constructs

(Figure 1). For example, the better children can regulate their own behaviour, emotion, and cognition, the better they can engage with their environment, and the more opportunities they will get to develop their EF skills. EF and self-regulation skills are dynamic processes that develop with time and through practice and experience (e.g., Lewis & Carpendale, 2009; Luria, 1966; Noble et al., 2013), and these skills ultimately influence each other throughout this developmental period.

It is also important to differentiate EF and regulation of cognition (a part of self-regulation: see Figure 1). Although these terms have been used interchangeably in the literature, in the current manuscript, they are viewed as separate entities, with executive functions being necessary for the regulation of cognition but also being used to reach goals outside of cognitive regulation (e.g., Heatherton & Wagner, 2011; Hofmann et al., 2012). For example, if individuals notice that they are engaging in rumination and want to stop, they can attempt to regulate their cognition by inhibiting certain thoughts, or trying to bring up alternative, more balanced thoughts to mind, both of which require the use of executive functions. However, executive functions can also be used to plan a vacation, which does not necessarily require regulation of cognition.

Important Issue Around Measurement of EF Skills

Over the years, a vast range of measures have been developed and used to assess EF skills in children. These measures range from child performance measures, such as laboratory tasks like the Wisconsin Card Sorting Task (WCST: Heaton et al., 1993) to informant-based questionnaires and reports, such as rating measures like the Behavior Rating Inventory of Executive Function (BRIEF: Gioia et al., 2000a). Although both informant- and performance-based measures may assess what has been referred to as executive functions, these measures are poorly correlated and evaluate very different aspects of cognitive and behavioural functioning

(McAuley et al., 2010; Ten Eycke & Dewey, 2016; Toplak et al., 2013). For example, performance-based measures typically require the use of controlled, structured, and standardized tasks to gather information regarding an individual's EF skills within an optimal environment. These measures often rely on accuracy and response time as measures of EF and are more concerned with the efficacy with which one processes information (e.g., Toplak et al., 2013). Meanwhile, informant-based questionnaires, also called rating measures, provide a measure of everyday EF skills as assessed by an informant, usually a teacher or a caregiver. Rating scales often provide information on the frequency and quality of observable behaviours that would indicate the use of EF skills in day-to-day activities and are not limited to performance in a one-on-one setting. Due to this, informant-based measures have often been described as providing a more ecologically valid measure of EF (e.g., Gioia et al., 2002a; Kenworthy et al., 2008; McAuley et al., 2010).

Despite providing valuable information on EF, the lack of overlap between informant- and performance-based measures can make it challenging to compare results across studies that have used different types of measures. Being aware of this measurement challenge in the field of EF is important and can help to understand some of the confounding results in the literature (e.g., McAuley et al., 2010). In the current manuscript, the type of measures used to assess EF will be specified to reduce confusion. Specifically, chapter 2 will focus on informant-based measures to gain a better understanding of everyday EF skills and related constructs (e.g., emotion control) in children with ASD. Meanwhile, chapter 3 will pay specific attention to which types of measures were used to assess progress in EF and emotion regulation skills in children with ASD undergoing interventions aimed at improving various aspects of regulation and EF.

Core Executive Functions

Given the breadth of the EF construct and the challenges surrounding it, it is helpful to break EF down into distinct and separable executive function domains that can be individually examined. One model that has dominated the EF literature (for review, see Best & Miller, 2010) is Miyake's tripartite model (Miyake et al., 2000). In his model, Miyake proposes three core EF skills: (1) inhibition, (2) updating/working memory, and (3) cognitive flexibility. These three separable but correlated top-down brain processes are thought to build on each other to create more complex executive functions such as problem solving, reasoning, and planning and organizing (Collins & Koechlin, 2012; Diamond, 2006; Miyake et al., 2000). Although this conceptual model of EF evolved from the adult literature, support has also been found in children's studies (e.g., Garon et al., 2018; Lehto et al., 2003). Each of the three core executive functions is defined below.

Inhibition, also known as inhibitory or interference control (Diamond, 2014), is a multifaceted construct that includes the ability to interrupt and stop an ongoing or predominant response, to ignore external distractors, to control motor activities, direct attention, and to manage impulsivity (Diamond, 2013; Friedman & Miyake, 2004). It plays a very central role in inhibiting behaviour and actions, and regulating emotions (Diamond, 2002; Jahromi & Stifter, 2008; Jahromi et al., 2013; Kochanska et al., 1998; Stifter et al., 1999; Thompson, 1994). Inhibition is one of the first EF skills to develop (Diamond & Taylor, 1996; Gerstadt et al., 1994; Kirkham et al., 2003) and is essential for the effective development of other EF skills (Barkley, 1997; Christoff et al., 2003; Diamond, 2000). Poor inhibition skills have also been linked to higher rates of externalizing behaviours (Livesey et al., 2006), worse health outcomes, lower levels of happiness, and higher rates of crime (Moffitt et al., 2011). Chapter three will focus

specifically on the close relationship between inhibition and emotion regulation challenges, and how this may be a promising avenue for interventions for children with ASD.

Working Memory, also at times referred to as updating (Miyake et al., 2000; St Clair-Thompson & Gathercole, 2006), is the ability to maintain and manipulate information (e.g., visual, auditory, spatial) in one's mind for a short period of time (Baddeley & Hitch, 1994). Working memory is critical for integrating and relating information from the past to the future and plays an important role in reasoning and decision making (Diamond, 2014; Swanson, 2011). For example, when problem solving, an individual must integrate current information with previous information, while simultaneously keeping in mind the desired future outcome. Working memory is also important for children when remembering rules of games and engaging with peers (e.g., Austin et al., 2014; Carlson et al., 2002; Keenan et al., 1998), and for following through on multi-step demands or requests (e.g., Jaroslawka et al., 2016). In the context of self-regulation, working memory skills can play an important role especially with regards to remembering and activating adaptive emotion regulation strategies (e.g., using cognitive restructuring techniques, or to redirect attention to other more pleasing mental contents) and in keeping in mind and adapting one's goal to a given situation (e.g., Hofmann et al., 2012; Schmeichel et al., 2008).

Cognitive flexibility, also known as shifting or set/task switching (Diamond, 2014), refers to the ability to switch between tasks, redirect attention, and to think about multiple concepts at once (Miyake et al., 2000). Cognitive flexibility plays an important role in adapting and adjusting to new information, and in dealing and coping with unforeseeable situations and setbacks (e.g., Hund & Foster, 2008). It can prevent individuals from becoming "stuck" and allows one to have a flexible approach to problem solving. Furthermore, cognitive flexibility has

been linked to creativity, as children must use their shifting abilities when trying to come up with novel ideas or when engaging in creative play (e.g., Filippetti & Krumm, 2020; Krumm et al., 2018). To effectively engage in cognitive flexibility, inhibition and working memory skills are often needed (e.g., Diamond, 2013; Filippetti & Krumm, 2020; Stoet & López, 2010). For example, if a child is asked to transition from one task to another, the child must first inhibit what they are doing while at the same time remembering what they were asked to transition to. Cognitive flexibility also plays a role in regulation, where it is especially helpful when adapting to unpredictable situations or when needing to change regulation strategies if one is not working effectively (e.g., Hofmann et al., 2012).

Executive Functioning and Self-Regulation in ASD

As mentioned earlier, ASD is a complex neurodevelopmental disorder marked by high levels of heterogeneity in clinical presentation. Over the years, many researchers have attempted to find a single theory that could account for this broad clinical presentation. The field has been mostly dominated by cognitive theories such as the weak central coherence theory (i.e., challenges in processing information within a larger context: Frith, 1989; Frith & Happé, 1994), theory of mind (i.e., challenges in the ability to ascribe mental states to one self and to others: Baron-Cohen et al., 1985), and the theory of executive dysfunction (i.e., challenges in EF skills are at the core of the symptoms of ASD: Hughes & Russell, 1993; Ozonoff et al., 1991; Pennington et al., 1997). However, mixed support has been found for these three theories, as not all individuals with ASD present with significant challenges in these cognitive areas (e.g., for review see Hill, 2004; Russo et al., 2007; Tager-Flusberg, 2007). It is now well accepted that on their own, these different theories, are not sufficient to explain the wide range of clinical presentation in ASD, and that it may be more suitable to view ASD as a collection of challenges

in multiples areas of cognition (Happé et al., 2006; Pellicano, 2010; Pellicano et al., 2006). Theory of mind, central coherence, and executive functions are all dynamic processes that develop over time and are influenced by wide array of factors including real world experiences. Additionally, there is fluidity among these developing systems as they likely influence each other and develop together (e.g., Karmiloff-Smith, 2009; Pellicano, 2010; Tager-Flusberg & Joseph, 2005). To try to understand such a complex neurodevelopment disorder with a single theory would fall short of appreciating the broad spectrum of strengths and challenges that individuals with ASD have. However, trying to intervene at all these levels at once would be overwhelming and likely very difficult to accomplish.

In the current manuscript, the focus is specifically on core executive functions and closely related constructs (i.e., self-regulation), and trying to understand their presentation in children with ASD, while also examining existing support for targeted interventions in these areas. Although challenges in EF are not present in all children with ASD and not unique to this neurodevelopmental disorder (e.g., EF challenges are also common in other neurodevelopmental disorders such as attention deficit hyperactivity disorder (ADHD); for review see Willcut et al., 2005), there is an agreement that the majority of individuals with ASD do present with challenges in at least some aspects EF (e.g., for review see Demetriou et al., 2018; Kenworthy et al., 2008). These results have been found in studies using both performance-based tasks (e.g., Kenworthy et al., 2008; Kenny et al., 2019) and rating measures (e.g., Van Eylen et al., 2015; Vogan et al., 2018) of EF, and to have broad ranging impacts on this population.

Executive functions have been shown to be predictive of ASD symptomology and severity (e.g., Pellicano, 2013). For example, difficulties with inhibiting ongoing response, shifting between tasks, and holding various information in mind have all been shown to be linked

to the rigidity in patterns of behaviours and specific interest observed in individuals with ASD (e.g., Hill, 2004; Kercood, et al., 2014; Lopez et al., 2005; Turner, 1997). Additionally, difficulty inhibiting one's own perspective to appreciate the perspective of others, and rigid thinking patterns have both been associate with challenges in theory of mind (e.g., Bock et al., 2015; Jones et al., 2018; Kenny et al., 2019; Lewis-Morrarty et al., 2012; Pellicano, 2010, 2013; Willinger et al., 2011), which is in turn associated with deficits in social communication and interaction (e.g., Joseph & Tager-Flusberg, 2004). Links between aspects of self-regulation and theory of mind have also been demonstrated (e.g., Samson et al., 2012; Yu et al., 2021). In a seminal study, Pellicano (2010) demonstrated that EF skills were predictive of the development of theory of mind abilities in children with ASD over a three-year period, but that the opposite (i.e., theory of mind skills predicting development of EF) was not supported. These results indicated that EF skills play an important role in the effective development of theory of mind abilities and subsequent social skills in children with ASD (e.g., Pellicano, 2010; Tager-Flusberg & Joseph, 2005). Delays in the development of EF skills will likely have rippling effects on other areas of functioning in ASD. Fisher and Happé (2005) demonstrated that a short intervention targeting EF skills was beneficial at improving theory of mind in children with ASD, making EF a good candidate for targeted interventions.

Challenges in EF are not only linked to core ASD symptoms but also to other key factors that contribute to the wide clinical presentation of ASD. More specifically, links between EF skills, and adaptive skills (e.g., Gardiner & Iarrocci, 2018; Kenny et al., 2019; Pugliese et al., 2015, 2016), communication and language skills (e.g., Friedman & Sterling, 2019; Udhnani et al., 2020), and academic performance (e.g., Ameis et al., 2022) in children with ASD, have all been demonstrated. Additionally, EF skills directly or indirectly, through their close link to self-

regulation, are likely also contributing to the high rate of co-occurring mental health, neurodevelopmental, and behavioural challenges observed in individuals with ASD (APA, 2013). Researchers have shown that individuals with ASD tend to engage in more maladaptive coping strategies, such as rumination, avoidance, and suppression (Jahromi et al., 2012; Khor et al., 2014; Konstantareas & Stewart, 2006; Mazefsky et al., 2014), and use fewer effective strategies flexibly (Cai et al., 2018). In turn these may explain why over half of children with ASD are estimated to have co-occurring internalizing (e.g., emotional disorder such as anxiety and depression) and/or externalizing challenges (e.g., conduct problems) (view Totsika et al., 2011 for review). Furthermore, difficulties in self-regulation have been associated with elevated levels of self-injurious behaviour in children with ASD (Carter Leno et al., 2018; Martínez-González et al., 2022).

Together, these findings highlight the important role that EF, and subsequently self-regulation, play in the development and clinical presentation of children with ASD, and provide a promising avenue for support. In order to effectively support children with ASD, one must first understand the broad presentation of EF and self-regulation skills in this neurodiverse group, and then look at whether these skills can effectively be trained. The next two chapters will explore these two important aspects in greater details.

Chapter 2: Profiles of Core Executive Functions and Emotion Control in Children and Adolescents with ASD

Impairments in executive functioning and aspects of self-regulation, especially emotion regulation, have been thoroughly documented in children, adolescents, and adults with autism spectrum disorder (e.g., Bos et al., 2018; Cai et al., 2018; Craig et al., 2016; Dijkhuis et al., 2017; Geurts et al., 2004; Hill, 2004; Mazefsky et al., 2013, 2014; Wallace et al., 2016). It is the consensus that most individuals with ASD present with challenges in at least some aspects of emotion regulation and EF (for review see Cibralic et al., 2019; Kenworthy et al., 2008). However, the degree of those impairments across and within children with ASD is not well understood. This is mainly due to the broad range of confounding results found in the literature, especially with regards to EF skills in children with ASD (e.g., Hill, 2004; Kenworthy et al., 2008; Russo et al., 2007). Challenges in methodologies, such as inconsistency in the definition of EF constructs, the difference in results based on the type of tools used to measure EF, and the lack of appreciation for the broad spectrum of EF skills in children with ASD, have all contributed to this issue of mixed findings in the literature. Additionally, only a handful of studies have simultaneously examined EF and emotion regulation (or other components of self-regulation) in children with ASD (e.g., Cibralic et al., 2019; Jahromi et al., 2013; Zantinge et al., 2017), limiting our knowledge of their presentation and interaction in this neurodiverse group. Gaining a better understanding of the presentation of EF and emotion regulation skills in children with ASD could provide valuable insight in how to support the development of these critical skills, while also helping health care professionals, educators, and support workers working with these children and their families better understand areas of needs.

Understanding Mixed Findings in ASD Literature

Within the EF literature, decades of research have focused on trying to identify the unique cognitive profile of individuals with ASD (e.g., Blijd-Hoogewys et al., 2014; Verté et al., 2006; Wallace et al., 2016). Research has specifically tried to differentiate EF challenges in ASD from those of other neurodevelopmental disorders, such as attention deficit hyperactivity disorder (ADHD), and from typically developing (TD) children (e.g., Benallie et al., 2021; Bramham et al., 2009; Corbett et al., 2009; Geurts et al., 2004; Karalunas et al., 2018). No clear patterns of strengths or deficits have emerged for individuals with ASD as the number of contradicting results continues to grow (for review see Geurts et al., 2014; Hill, 2004; Kenworthy et al., 2008). These mixed findings are partly due to challenges associated with studying a broad construct with no universal definition (Baggetta & Alexander, 2016; Goldstein et al., 2014), and with using measures that assess distinct aspects of executive functions (Ten Eycke & Dewey, 2016; Toplak et al., 2013). Meanwhile, although emotion regulation is also a broad construct, less conflicting findings exist in the literature, as there seems to be a more generally accepted view that emotion regulation skills can vary greatly across children with and without ASD (e.g., Zeman et al., 2006). However, adequate emotion regulation skills rely heavily on EF (e.g., Jahromi, 2017; Zelazo & Cunningham, 2007), and thus the mixed findings in EF skills in children with ASD are also impacting the understanding of ASD presentation and co-occurring challenges in EF and emotion regulation.

Being aware of differences between measurement types (e.g., informant-based versus performance measures) and looking at EF as a construct that can be broken down into distinct and separable executive function domains, instead of an all-encompassing construct, has helped with measurement challenges. However, even when looking at individual components of EF

skills (e.g., inhibition, working memory, cognitive flexibility) and only looking at one type of measurement tool, differences in the literature still exists. The range of contradicting results can be seen in a study conducted by Kenworthy and colleagues (2008), who performed a literature review of studies assessing EF skills in ASD. The authors separated the included studies based on the domain of EF assessed and measurement type (e.g., real-world/informant-based measures versus laboratory/perform-based measures). Across the studies included in the review results were inconsistent with some indicating that the ASD group performed similar to, better than, or significantly worse than the comparison groups in their respective studies, even when looking at the same EF domain assessed using comparable measures (see Tables 1 and 3 in Kenworthy et al., 2008).

More than a Measurement Challenge

It is possible that the mixed results found in the literature regarding EF skills are more than just a result of measurement challenges, and actually reflect high level of heterogeneity in these skills across children with ASD. ASD is a complex neurodevelopmental condition marked by a spectrum of symptoms and abilities, creating a broad range of clinical presentations (Masi et al., 2017). Children with ASD can vary in terms of their language (i.e., ranging from nonverbal to fluent speech), cognitive (i.e., ranging from significantly impaired to superior abilities), and adaptive skills (i.e., ranging from requiring substantial support to being independent) (see Rosen et al., 2021 for more details). Given this, it should be expected that a wide range of EF abilities also exists within this population. It is important that researchers looking at EF skills in children with ASD start to use approaches that take into consideration this heterogeneity.

Heterogeneity in ASD is especially important to consider when selecting the appropriate tools to measure variables of interest. With regards to EF specifically, laboratory-based measures

may not be well suited for everyone on the autism spectrum, as these tasks often put high demands on language comprehension, communication skills, motor skills and other various cognitive abilities (e.g., processing speed) which have all been shown to vary greatly across the autism spectrum (e.g., APA, 2013; Rosen et al., 2021). For example, motor skills have been shown to be highly correlated to performance on laboratory tasks for EF (e.g., Piek et al., 2004; Ten Eycke & Dewey, 2016; Wuang et al., 2011). Therefore, tasks that require a motor response and where response time is used to determine the level of deficit in a particular executive function (e.g., Go/No-Go task: Livesey & Morgan, 1991; Luria, 1959 or the Walk/Don't Walk task: Manly et al., 1999), may put certain children with ASD at a disadvantage given the higher rates of motor delays in this clinical group compared to TD children (e.g., Lloyd et al., 2013). Similarly, the Stroop task (Stroop, 1935) where individuals are asked to ignore the colour word that is spelled out while trying to name the colour of the ink in which it is written, requires individuals to have adequate reading and communication skills, in addition to proper language comprehension skills. Although variations of the Stroop tasks have been developed for children who have yet to acquire reading abilities (e.g., Animal Stroop task: Wright et al., 2003), challenges can remain in the context of instruction comprehension. Meanwhile, although children on one end of the spectrum may be disadvantaged by performance-based measures, those with stronger abilities have been shown to have performed better in structured compared to unstructured environments (Gioia et al., 2002a; Mesibov et al., 2005; Van Eylen et al., 2015; White et al., 2009). This ability to perform better in structured settings has led to challenges in sensitivity where more subtle variation in EF skills is not always picked up by performance-based measures. Measures of EF skills in everyday life (e.g., informant report and rating scales) have been argued to detect EF challenges even when laboratory-based performance measures did

not (e.g., Kenworthy et al., 2008; Spek, 2010). Although these measures are known to assess very different aspects of EF (Toplak et al., 2013), informant-based measures might be better suited to obtain information on day-to-day EF skills across the whole autism spectrum.

In the current study the Behavior Rating Inventory of Executive Function (BRIEF: Gioia et al., 2000a) is used to gather information on EF and emotion control skills in children with ASD. The BRIEF is one of the most commonly used informant-based tools for measuring executive and regulation skills and behaviours in children. It provides a measure of how well individuals use their executive and regulation skills to navigate their everyday environment. Data obtain from this questionnaire can be separated into individual domains of EF and regulation (e.g., inhibition, shifting, working memory, and emotion regulation), while also providing information on these broader constructs. The BRIEF can easily be administered to caregivers of children with ASD with a wide range of abilities, as the children themselves are not required to fill out the questionnaire (except for the self-report version of the BRIEF). The caregiver-form of the BRIEF has been commonly used to evaluate executive and regulation abilities children with ASD (e.g., Blijd-Hoogewys et al., 2014; Granader et al., 2014; Kenworthy et al., 2005; Panerai et al., 2014). Findings across these studies demonstrate variability across BRIEF domain scales. For example, Blijd-Hoogewys and colleagues (2014) found that more than half of the children in their study with ASD (66%) presented with clinically significant deficits on the shifting subscale of the BRIEF and even fewer with challenges in inhibition, emotion control, and working memory. These results, along with those of other studies that have used the BRIEF, support the notion that most, but certainly not all, children with ASD present with at least some difficulties in EF but that these challenges vary greatly within this group (e.g., Baez et al., 2020; Blijd-Hoogewys et al., 2014; Dajani et al., 2016).

Embracing Heterogeneity in Statistical Analyses

Despite the well-accepted notion that ASD is a wide spectrum and the growing appreciation for variability in EF and emotion regulation skills across children with ASD, most researchers continue to use statistical measures that fail to take this heterogeneity into consideration. Statistical analyses used in studies on ASD often rely on mean values to make conclusions. Although these methods are important, they can limit the understanding of the broad range of abilities within clinically diverse populations, especially when a single value, like the mean, is used to represent this large variability in skills. Fortunately, statistical methods have been developed to help with the analyses of heterogenous samples, such as person-centered approaches.

Person-Centered versus Variable-Centered Approaches

Variable-centered approaches are commonly used in psychological research and are important for answering questions that look at how predictor variables can explain variance in outcomes (Bergman & Trost, 2006; Howard & Hoffman, 2018). They use analytical procedures (e.g., correlation, regressions, analysis of variance) that operate under the assumption that the population from which the sample is drawn is homogenous with regards to how variables of interest operate with each other (Bergman & Magnusson, 1997; Laursen & Hoff, 2006). However, variable-centered approaches may not be best suited when dealing with a high degree of heterogeneity, especially given that these practices often use group averages. In these cases, a person-centered approach (e.g., latent profile or cluster analyses) may be a better option. Person-centered approaches attempt to identify homogenous subgroups, within a heterogeneous population, based on shared or similar patterns of relationships between variables of interest (Magnusson, 2003). Instead of looking at group means across a sample, person-centered

approaches consider each participant on an individual level, and then group individuals who share similar patterns of skills together, creating homogenous subgroups. Findings from a person-centered approach can be generalized to the person instead of the variable and thus be more easily used to inform treatment and interventions (Magnusson, 2003). Given the fact that both EF and emotion regulation skills can be trained (Diamond, 2012; Diamond et al., 2007; Weiss et al., 2018), and the heterogeneity in the presentation of these skills in children with ASD, a person-centered approach that would identify various profiles in this population could be extremely informative.

Research in the field of ASD has already started to pivot towards a person-centered approach given the high degree of variability in ASD presentation (e.g., Baez et al., 2020; Dajani et al., 2016; Garon et al., 2018; Munson et al., 2008; Préfontaine et al., 2022; Pulsipher & Lieb, 2022; Sullivan et al., 2019; Zheng et al., 2019). Using a person-centered approach, Dajani and colleagues (2016) found three distinct EF profiles ("above average", "average", and "impaired") in a large mixed sample of school-age children with diagnoses of ASD, ADHD, and ASD and ADHD combined, along with TD peers. The profiles were created based on subdomain scores from the BRIEF and performance-based measures, and looked specifically at inhibition, shifting, working memory and planning/organizing domains of EF. Results indicated that 47% of the ASD sample fell in the "impaired" profile, while 46% fell in the "average" profile, and a small minority (7%) fell in the "above average" profile. In a similar study, looking at a mixed sample of children with and without ASD and using all eight subdomains of the BRIEF, Baez and colleagues (2020) also found that the same three profiles emerged. In this study, ASD children made up 92% of the "impaired" profile, 31% of the "average" profile, and about 5% of the "above average" profile (Baez et al., 2020). Both studies demonstrated that children with ASD

present with variability in EF skills, ranging from above average to impaired, supporting the utility of using a person-centered approach when looking at EF skills. However, neither study looked at a purely ASD sample, as data from TD participants were always combined with those of participants with ASD when running the analyses. To my knowledge, no study to date has looked exclusively at trying to create core EF profiles in a sample of only children with ASD to parse out heterogeneity within this specific population. Additionally, the role of emotion control and its relation to core executive functions in children with ASD has not yet been explored using a person-centered approach. Looking at these profiles in a solely ASD sample could provide more information regarding which subgroup of children with ASD may require more targeted interventions in emotion regulation and EF.

Current Study

Using a person-centered analysis, the current study aimed to determine whether homogenous subgroups exist in children with ASD based on core EF and emotion regulation skills, and how these subgroups may vary based on ASD symptoms and other known variables related to this broad clinical spectrum. The focus is specifically on core EF abilities (i.e., inhibition, working memory, and cognitive flexibility) and emotion control. These executive functions have been argued to be distinct but highly correlated skills that serve as the foundation of more complex skills (Diamond, 2006; Lehto et al., 2003; Miyake et al., 2000) and have been linked to emotion regulation skills in ASD (e.g., Mazefsky et al., 2013). The current study aimed to answer the two following research questions:

1) Do distinct profiles based on caregiver report of everyday core EF skills (i.e., inhibition, working memory, cognitive flexibility) and emotion control abilities exist in children with ASD?

2) What variables previously linked to EF and emotion regulation challenges in children with ASD (i.e., adaptive skills, behavioural and emotional challenges, intelligence, age, biological sex, and ASD symptoms) can predict profile membership?

Previous research using person-centered approaches with children with ASD have been successful in identifying homogenous subgroups within this population based on different variables such as ASD symptoms (Georgiades et al., 2013) and reading skills (McIntyre et al., 2017). Given the existing literature supporting heterogeneity in EF skills in children with ASD, it was hypothesized that at a minimum of two distinct profiles will be found, differentiating children with clinically significant challenges in core executive functions and emotion control from those without these challenges. It was predicted that not all children with ASD in the current sample will present with clinically significant challenges in all core EF and emotion control skills, but this will represent a small minority of the sample. Meanwhile, it was predicted that a second profile depicting challenges in at least some areas of core executive function and/or emotion control would also emerge, representing a larger proportion of children with ASD. Given that person-centered analyses are exploratory in nature, no specific hypotheses were made regarding how individual core executive functions and emotion control skills will come together across the various profiles. With regards to the second research question, it was hypothesized, based on previous studies, that children with more severe ASD symptoms (de Vries & Geurts, 2012; Van Eylen et al., 2015), greater challenges in adaptive skills (Gilotty et al., 2002; Pugliese et al., 2015), and higher levels of behaviour and emotional challenges (Vogan et al., 2018) would be linked to the profile with the greatest EF and emotion control difficulties. No hypotheses regarding the effect of age, intelligence, or gender on group membership across the profiles were

made given the contradicting results in the ASD literature (e.g., Friedman et al., 2006; Kirkovski et al., 2013; Van Eylen et al., 2015).

Methods

Participants and Database

A total of 256 children with ASD between the ages of 6 and 18 years old (*M* = 128.34 months, *SD* = 34.37) were included in the current study (view Table 1 for demographics). 75.8% of the participants were male (n =194), which is consistent with the four to one ratio of male to female in children with ASD (APA, 2013). Participants' data were obtained from the National Institute of Mental Health (NIMH) Data Archive (NDA), which is a nation-wide database site in the United States that provides data from de-identified human subjects for the purpose of encouraging scientific research and discovery through data sharing. Participants came from four different studies included in the National Database for Autism Research (NDAR)[1]. The NDAR is a collaborative informatics systems created by the National Institute of Health to provide a national resource to support and accelerate research in autism. The NDAR was selected because it contains a large number of datasets from studies examining various aspects of the development of children with ASD. Datasets were selected based on three criteria: a) included data from children with a confirmed diagnosis of autism spectrum disorder between the ages of 5 and 18 years old; b) included raw scores from the caregiver-scale of the school-aged BRIEF questionnaire, and c) included a measure of cognitive abilities. Datasets with similar measures of autism symptoms (e.g., Social Responsiveness Scale; Autism Diagnostic Observation Schedule),

[1] Data used in the preparation of this article were obtained from the NIH supported National Database for Autism Research (NDAR). NDAR is a collaborative informatics systems created by the National Institute of Health to provide a national resource to support accelerate research in autism. This manuscript reflects the views of the author and may not reflect the opinions or views of the NIH or of the Submitters submitting original data to NDAR.

emotional and behavioural challenges, and cognitive functioning were prioritized. All included participants were required to have a score in the clinical range on either the Autism Diagnostic Observation Schedule (Lord et al., 2000, 2012) or the Autism Diagnostic Interview (Lord et al., 1994; Rutter et al., 2003). These measures are considered gold-standard diagnostic tools for ASD (e.g., Risi et al., 2006; Wiggins et al., 2015), and will be explained in greater details in the next section. All data in the NDAR come from children whose guardians have provided consent for their de-identified information to be available within the data archive. Given that the NDAR uses a global unique identifier for each research participant, the four datasets were compared to ensure that there was no duplication of participants. Only five participants appeared in more than one dataset, and for these participants, the dataset containing the earliest version (e.g., when the participant was the youngest) was kept, limiting the impact of any test re-test effects.

Measures

Across all datasets, only information needed to answer the current research questions were extracted. Specifically, information regarding children's EF skills, autism symptoms, adaptive functioning skills, emotional and behavioural challenges, and cognitive abilities were of importance. Additionally, relevant demographic information such as age and gender were also included. Most of the data used in the current study came from informant-based measures.

Measures of ASD symptoms

Depending on the dataset, different measures of autism symptoms were collected. All four studies used the Autism Diagnostic Observation Schedule, second edition (ADOS-2: Lord et al., 2012)[2] as their primary measure to confirm ASD diagnosis. The ADOS-2 is a semi-structured

[2] Six participants were administered the earlier version of the ADOS (Lord et al., 2000).

standardized assessment tool used to diagnose ASD across all ages and developmental level. Using play-based activities and questions, the ADOS-2 gathers information on an individual's communication and reciprocal social interaction skills, and restricted repetitive patterns of interest and behaviours (Lord et al., 2012). The Autism Diagnostic Interview- Revised (ADI-R: Rutter et al., 2003) was also used in two of the four studies and provided additional information regarding the severity of symptoms that the participants presented with. The ADI-R is a semi-structured standardized interview performed with the caregiver which collects information on an individual's presenting symptoms linked to ASD. Higher scores on the different sections of the ADOS-2 and ADI-R are associated with more severe presentation of ASD symptoms. Both measures were used in the current study to confirm ASD diagnosis for all included participants.

Data from the Social Responsiveness Scale- Second edition (SRS-2: Constantino & Gruber, 2012), a standardized caregiver-based questionnaires that collects information on the presence and severity of social impairment and repetitive patterns of behaviour, was also collected in three of the four datasets. The SRS-2 provides five treatment scales (Social Awareness, Social Cognition, Social Communication, Social Motivation, and Restricted Interest and Repetitive Behaviour), a total score, and two DSM-5 compatible subscales: (1) Social Communication and Interaction, and (2) Restricted Interest and Repetitive Behaviour. Total T-scores of 59 and below are considered to indicate low to no ASD symptoms, scores between 60 and 65 indicate mild to moderate symptoms, scores between 66 and 75 are considered moderate, and T-scores above 75 indicate severe and strongly associated with ASD symptomology (Constantino & Gruber, 2012). The data from the SRS-2 were used to determine whether the presence and severity of ASD related symptoms was linked to the different profiles.

Executive Functioning Measure

The BRIEF (Gioia et al., 2000a) is a questionnaire used to measure everyday EF skills. In the current study, all participants were required to have data from the caregiver/parent form of the school-age version of the BRIEF which was designed for children between the ages of 5 to 18 years old. This questionnaire contains 86-item presented in the form of a statement (e.g., "Overreacts to small problems") that caregiver must scored as either Never (score of 1), Sometimes (score of 2), or Often (score of 3). Each item corresponds to one of eight clinical scales: Inhibition, Working Memory, Shifting, Emotional Control, Initiation, Organization/Planning, Organization of Material, and Monitoring. In addition, these clinical scales can be combined to form two broader indexes scores, Behavioural Regulation Index (BRI) and Metacognition Index (MI), and an overall composite score, Global Executive Composite (GEC). Depending on the analyses, either the raw scores or the T-scores (standardized based on age and gender) of the clinical scales were used. Higher raw scores and T-scores indicate higher levels of impairment. T-scores of 65 or above indicate clinically significant concerns, while T-scores between 60 and 64 indicate at-risk concerns, and those below 60 indicate no concerns. The caregiver version of the BRIEF is a well-studied tool that has been shown to have good internal consistency (alphas = 0.80 to 0.97) and good test-retest reliability (r = 0.82) (Gioia et al., 2000b). Additionally, the BRIEF has been shown to have good to excellent construct and criterion validity across different neurodiverse samples (e.g., Traumatic Brain Injury: Donders et al., 2010; ADHD and Tourette Syndrome: Mahone et al., 2002) and is a commonly used method in both research and clinical assessments.

Cognitive Measures

Information regarding the participants' cognitive skills was obtained from standardized measures of intelligence. Three of the four datasets used the Wechsler Abbreviated Scale of Intelligence- 2nd Edition (WASI-II: Wechsler, 2011), while one used the Differential Ability Scale- 2nd Edition (DAS-II: Elliott, 2007) as a measure of cognitive skills. The WASI-II is a reliable measure of intelligence that can be used for individuals between the ages of 6 up to 90 years old (Axelrod, 2002; McCrimmon & Smith, 2013), while the DAS-II can be used for individuals between the ages of 2 to 17 years old. Both measures have been shown to have adequate to excellent internal consistency (DAS-II: 0.74-0.96 and WASI-II: 0.87-0.91) and good convergent validity with other measures of intellectual abilities (for more information view Marshall et al., 2011; McCrimmon & Smith, 2013). Convergent validity between older versions of the DAS and the Wechsler Intelligence Scale for Children (WISC) has also been found (DiCerbo & Barona, 2000).

Equivalent scores from each measure of intelligence were determined in order to obtain a Full Scale IQ (FSIQ), Verbal IQ (VIQ), and a Nonverbal IQ (NVIQ) for each participant for whom an intelligence measures was administered (n = 246). All participants who were administered the WASI-II (n = 162) performed four subtests (Vocabulary, Similarities, Block Design, and Matrix), which were combined to obtain a measure of overall cognitive abilities (4-subscale FSIQ). The VIQ was made up of two subtests (Vocabulary and Similarities), as was the NVIQ (Block Design and Matrix). Meanwhile, participants who were administered the DAS-II (n = 84) performed six subtests (Word Definitions, Verbal Similarities, Matrices, Sequential and Quantitative Reasoning, Recall of Designs, and Pattern Construction) which were combined to provide an overall General Conceptual Ability (GCA) score which was used as the FSIQ in the

current study. The VIQ for the DAS-II was calculated using two subtests (Word Definition and Verbal Similarities), as was the NVIQ (Pattern Construction and Sequential and Quantitative Reasoning). Across the two measures, individual subtests were comparable (e.g., Word Definition from the DAS-II, and Vocabulary from the WASI-II). Additionally, other studies have used a combination of WASI-II and DAS-II scores when performing research with individuals with ASD (e.g., Arnett et al., 2020; Brookman-Frazee et al., 2019; Edgar et al., 2019; Martinez et al., 2022). Ten participants were missing information on their cognitive skills.

Adaptive Skill Measure

The Vineland Adaptive Behaviour Scale- Second Edition (VABS-2: Sparrow et al., 2005) is a caregiver rating questionnaire that gathers information on a child's overall adaptive functioning skills across the three broad domains of communication, daily functioning, and socialization. It provides standard scores based on age norms for each of the three domains scores and an overall Adaptive Behaviour Composite (ABC) score. Higher scores represent stronger adaptive skills and standard scores of 85 or above are considered within the average range. The VABS-2 is commonly used with children with ASD (e.g., Klin et al., 2007; Perry et al., 2009; Yang et al., 2016) and can provide a proxy for the level of ASD severity as the DSM-V categorizes autism severity based on support required for individuals to function within their environment (APA, 2013). Additionally, a relationship between EF skills and adaptive skills in children with ASD has been demonstrated (Gilotty et al., 2002; Pugliese et al., 2015, 2016).

Emotional and Behavioural Challenges Scale

The Child Behavior Checklist (CBCL: Achenbach, 1991) from the Achenbach System of Empirically Based Assessment (ASEBA) is a 113-item norm-referenced questionnaire that provides information on a wide range of emotional and behavioural challenges including anxiety,

depression, social problems, attention, aggression, and more. The CBCL is made up of eight syndrome scales that further group into two higher order factors: internalizing and externalizing problems. Previous research has demonstrated that the CBCL internalizing and externalizing factor structure is supported in children with ASD (Pandolfi et al., 2012) making this an appropriate scale to use as a complementary source of information regarding the possibility of co-occurring mental health challenges. Only the T-scores for the Aggressive Behaviour, Anxious Behaviour, and Attention Problem syndrome scales were included in the analyses of the current study as challenges in EF and emotion regulation skills in ASD have been specifically linked to challenges in attention, anxiety, and aggression specifically (e.g., Hollocks et al., 2014; Vogan et al., 2018). T-scores above 70 indicated clinically significant challenges, while scores between 65 and 70 indicated at-risk concerns. Three of the four datasets included data from the school-age caregiver form of the CBCL, which is suited for children between the ages of 6 to 18 years. The CBCL provided a measure of co-occurring behavioural and emotional challenges, which was used to determine whether additional challenges played a role in predicting membership profiles in children with ASD.

Statistical Analyses

Missing Data and Outliers

Given the fact that the current study combined data from multiple datasets, missing data were often a result of whether the original study for which the data was collected included the measure of interest or not. However, within individual datasets, data were expected to be missing at random. Missing or skipped items on the BRIEF questionnaires were dealt with in accordance with the BRIEF manual (Gioia et al., 2000a), which states that if no more than two items within a subscale are missing, then these missing items can be scored as one (i.e., Never). Similarly,

missing items for the SRS-2 were replaced by the median scores for that particular item as recommended by the manual (Constantino & Gruber, 2012). No other imputation of the data was conducted.

Outliers were dealt with using winsorization (Dixon, 1960), a value modification method where instead of discarding outliers, they are replaced by a value that would be considered within the normal distribution of the data (Ghosh & Vogt, 2021; Kwak & Kim, 2017). This method makes the underlying assumption that these extreme scores are likely an exaggeration of the truth instead of being an error. In the current study, extreme values were adjusted to be equivalent to three standard deviations away from the mean, which is commonly used in winsorization (Kwak & Kim, 2017). Overall, less than 0.01% of the data points were winsorized and no outliers were detected on any of the BRIEF subscales.

Preliminary Analyses

To my knowledge, the factor structure of the BRIEF has not yet been tested with a sample of children with ASD only. Previous confirmatory factor analyses (CFA) for the BRIEF have included children with a range of neurodevelopmental disorders and health conditions (e.g., Gioia et al., 2002b; Lyons Usher et al., 2016), including ASD. However, none has looked exclusively at children with ASD. Given that the profiles were to be constructed using the raw scores of the subscales of the BRIEF, it was important to ensure that the data fit the eight-factor model of the original scale (Gioia et al., 2000b). The CFA model was estimated using the *lavaan* package (Rosseel, 2012) in R (R Core Team, 2020) with robust full information maximum likelihood estimation (MLR). Consistent with recommended practice (Hu & Bentler, 1999), multiple indices of fit were used to evaluate how well individual items fit on each of the subscales. In the current study, the following indices of fit were used: (a) the Chi-squared (χ^2)

exact fit test; (b) the root mean square error of approximation (RMSEA); (c) the standardized root mean square residual (SRMR), (d) the Tucker Lewis index (TLI); and (e) the comparative fit index (CFI). Overall, smaller RMSEA and SRMR (< 0.08) and larger TLI and CFI (> 0.90) indicate better fit (Hu & Bentler, 1999). Meanwhile, Chi-squared tests should be non-significant to indicate good fit, but this measure is susceptible to sample size (Hayduk, 1987; Hayduk & Glaser, 2000).

Constructing the Profiles

A latent profile analysis (LPA), which uses a person-centered approach, was performed to gain a better understanding of profiles in core executive functions and emotion regulation skills among children with ASD. The raw scores of the Inhibit, Shift, Working Memory and Emotion Control subscales of the BRIEF were the variables used to construct the latent profiles. Raw scores represent the frequency (e.g., Never- score of 1, Sometime- score of 2, and Often- score of 3) and number of items endorsed by caregivers of children with ASD on each of the four subscales. Raw scores were selected over standardized score to be consistent with previous research examining EF skills in children with ASD (e.g., van den Bergh et al., 2014) and to gain a better understanding of everyday EF challenges in this population without adjusting scores based on age and gender norms of the TD population. Children with ASD have been argued to follow a different developmental trajectory than TD peers in various areas, including EF skills (Rosenthal et al., 2013; Van Eylen et al., 2015; Vogan et al., 2018), and thus adjusting for age and gender may unnecessarily remove variance in the profiles. Multiple linear regressions indicated that age of participants was not predictive of the total raw scores for the working memory, shift, and emotion control subscales in the current sample ($p > 0.145$). Meanwhile, age did predict the total raw scores on the inhibit subscale, with fewer items being endorsed or at a

lower frequency on the inhibit subscale as children got older ($\beta = -0.04$, $p < 0.001$). However, this significant result accounted for a very small proportion of the total variance observed (adjust $R^2 = 0.052$), and thus using raw scores would be appropriate as there was a minimal effect of age on these subscale scores within the current sample. Additionally, the latent profile analyses were repeated with the T-score of the four domain scales, and similar patterns of results emerged for the profiles (view supplemental Table 1 and Table 2 in Appendix A).

The LPA performs a series of analyses to determine the ideal number of profiles that fit the data best, starting with a one-profile model and systematically increasing the number of profiles for each subsequent analysis. Given the exploratory nature of the current study and consistent with recommended practice, a varying number of profiles (also referred to as classes) were performed (1-5 classes: Ferguson & Hull, 2018; Marsh et al., 2009). Additionally, three specifications of the variance-covariance structure (i.e., most restrictive to least restrictive) were used to select the best fit (Masyn, 2013). The different variance-covariance structures differ in the degree to which variance and covariance across groups are allowed to vary (Masyn, 2013). For example, Model 1 is the most restrictive model as the variance is fixed across groups and co-variance is set to zero (default model in R). In the second model, variance is allowed to vary across group while co-variance remains set at zero. Meanwhile, the least restrictive model allows both variance and covariance to vary across groups. These analyses were conducted using the *tidyLPA* package (Rosenberg et al., 2019) in R. To determine the optimal number of profiles several indices of fit were evaluated: (a) information criteria including the Akaike information criterion (AIC) and Bayesian information criterion (BIC); (b) bootstrap likelihood ratio test (BLRT); and (3) entropy (Nylund et al., 2007). Entropy provides a measure of distinction between individual profiles/classes, where a high entropy value indicates better distinction

(Celeux & Soromenho, 1996; Clark & Muthén, 2009; Nylund et al., 2007). Meanwhile, smaller values for other indices of fit (e.g., BIC and AIC) are indicative of better fit (Nylund et al., 2007). Examination of the theoretical interpretation of the latent profiles was also taken into consideration when determining the optimal numbers of profile (Masyn, 2013). For example, a profile with too few members may not provide much information.

Follow up analyses using one-way analyses of variance (ANOVA), or Pearson Chi-squared tests when dealing with categorical variables, were conducted to examine differences between profiles. Where appropriate, post-hoc comparisons were performed using a Bonferroni correction (0.05/3 = 0.017) to account for multiple groups comparison. Lastly, predictors of group membership were explored. For each participant in the current dataset, group membership was assigned using the highest value of posterior estimate, which indicates the probability of an individual belonging in one group/profile over the others (Clark & Muthén, 2009). Given that group membership is a categorical variable, multinomial logistic regressions were performed using the *nnet* package (Venables & Ripley, 2013) in R to determine whether variables previously related to EF and emotion regulation skills in children with ASD (e.g., age, biological sex, ASD symptoms, cognitive and adaptive skills, and emotional and behavioural challenges) could predict profile membership. Odd ratios, which in this case refers to the odds of participant belonging to one profile over another, were reported and interpreted for each significant predictor of group membership.

Results

A total of 256 participants were included in the current study. Descriptive data of the participants along with sample size for each measure can be found in Table 1. All variables used in the current analyses were normally distributed based on the skewness-kurtosis normality test.

The majority of participants (72%) were between the ages of 6 and 11 years old (*M* = 10 years and 8 months). Participants' FSIQ ranged from 56 to 153, with a small proportion of participants (2.4%) falling well below the average range (FSIQ ≤ 70). No significant difference between verbal and nonverbal IQ were noted. Most participants (69%) also presented with adaptive skills below the average range, indicating delays in overall daily functioning skills. With regards to EF skills, clinically significant challenges were reported by caregivers in 41.4% of the sample with regards to emotion control difficulties, 45.3% for inhibition, 62.5% for shifting, and 63.3% for working memory. Meanwhile, a small proportion of participants received clinically significant ratings on the CBCL for an internalizing (16%) and/or externalizing (9%) disorders (T-scores > 70).

Table 1. Descriptive Statistics

Variables	n	Mean	SD	Range	Skewness	Kurtosis
Age (months)	256	128.34	34.37	76-218	0.90	0.01
Intellectual Abilities (standard scores)*						
Verbal IQ	245	99.98	18.13	52-155	0.19	0.23
Nonverbal IQ	245	102.61	17.07	57-154	0.32	-0.20
Full Scale IQ	245	101.15	17.09	56-153	0.22	-0.15
BRIEF subscale (T-scores)						
Inhibit	256	63.48	13.46	36-97	0.11	-0.89
Emotion Control	256	60.98	12.63	36-91	-0.05	-0.76
Shift	256	67.70	13.43	36-99	-0.18	-0.27
Working Memory	256	66.86	11.21	36-92	-0.45	-0.23
BRIEF Indices (T-scores)						
Behavioural Regualtion Index (BRI)	256	65.76	13.28	37-96	-0.05	-0.57
Metacognition Index (MI)	256	65.87	11.33	32-91	-0.35	-0.25
Global Executive Composite (GEC)	256	67.10	11.74	34-94	-0.31	-0.21
CBCL (T-scores)						
Internalizing Domain	209	61.04	9.72	34-86	-0.29	-0.44
Externalizing Domain	209	56.45	10.41	33-79	-0.21	-0.65
Vineland (Standard Score)						
Communication Domain	211	82.27	14.53	39-120	-0.02	-0.10
Living Skills Domain	212	82.28	13.79	47-124	0.01	-0.16
Socialization Domain	212	75.34	13.10	40-115	0.02	0.37
Adaptive Behaviour Composite (ABC)	212	78.20	12.22	41-110	-0.10	0.03
SRS-2 (T-score)						
Social Communication and Interaction	185	71.88	9.99	43-92	-0.19	-0.43
Restricted Interest and Repective Behaviour	185	71.85	12.83	45-110	0.28	-0.14

Note. *Intellectual abilities was either measured using the WASI-II (n= 162), or the DAS-II (n= 84).

Confirmatory Factors Analysis for the BRIEF

To ensure that individual items on the BRIEF mapped onto the eight subscales, a confirmatory factor analysis of the 8-factors model was performed using the data from the 256 ASD participants. The Cronbach's alpha coefficients for each of the eight-subscales ranged from 0.77 to 0.92 (see Table 2), indicating adequate to excellent reliability and internal consistency (Sarmento & Costa, 2017). Correlations between subscales ranged from moderate to high (r = 0.37 to 0.77), with subscales falling under the same Index domain (e.g., Metacognition Index, Behavioural Regulation Index) typically being more highly correlated than items across indexes (Table 2). Overall, the results indicated that the 8-factor model fits the data well with CFI = 0.981, TLI = 0.980, RMSEA = 0.056 (90% CI: 0.054, 0.059), and SRMR= 0.075. The Chi-squared yielded significant results ($\chi^2 = 5284.77$, $p < 0.000$), and is not a significant concern as this is likely an effect of the larger samples size (Hayduk, 1987; Hayduk & Glaser, 2000). Together, these results indicate that, in a sample of children with ASD, the individual items from the BRIEF do map on to the eight subscales domains described in the scale, demonstrating good validity. Therefore, the raw scores of these subscales can be used to explore profiles of core executive functions and emotion regulation in children with ASD.

Table 2. Mean, Standard Deviation, Correlation, and Reliability of the Eight BRIEF Subscales.

	Mean (SD)	1	2	3	4	5	6	7	8
1. Inhibit	20.30 (5.68)	*0.92*							
2. Shift	16.86 (3.82)	0.53	*0.85*						
3. Emotional Control	20.34 (5.34)	0.64	0.71	*0.91*					
4. Working Memory	22.70 (4.78)	0.55	0.49	0.43	*0.89*				
5. Initiate	17.20 (3.61)	0.37	0.50	0.42	0.68	*0.77*			
6. Planning/Organization	26.30 (5.83)	0.47	0.54	0.43	0.77	0.76	*0.89*		
7. Organization of Materials	13.74 (3.41)	0.44	0.39	0.41	0.53	0.52	0.61	*0.87*	
8. Monitor	18.32 (3.74)	0.64	0.55	0.54	0.67	0.64	0.70	0.54	*0.82*

Note. Total raw scores of BRIEF subscales. Bolded items (1-4) represent scales used in LPA. Coefficient alpha are italiziced and listed on the diagonal for all applicable scales. All correlation values were significant at $p < .001$.

Profiles of Core Executive Functions and Emotion Control in Children with ASD

The summary of the fit indices for all models of the latent profile analysis are presented in Table 3. Models where variance between groups was allowed to vary while covariance remained fixed at zero could not be estimated and thus results from this variance-covariance structure model were not reported. For the least restrictive variance-covariance factor structure, the BIC values kept increasing with each increase in the number of profiles added, indicating poor fit (see Table 3). Therefore, the most restrictive factor structure with equal variance across profiles and covariance set at zero was retained as the optimal parametrization. Examination of the indices of fit for the different models within the restrictive factor structure, indicate that a three-profile model was optimal (Table 3). The three-profile model fits the data well, shows good distinction between the three profiles as shown by the entropy value, has an adequate number of participants in each profile (smallest group has n = 41), and the profiles differed from one another based on levels of core EF skills (view Figure 1 and Table 3).

Table 3. Indices of Fit for all Models per Variance-Covariance Structure as Derived from LPA

Model	BLRT(p value)	AIC	BIC	Entropy
Equal variance and coviance set at zero				
One-Profile	n/a	6152.11	6180.47	1
Two-Profile	0.01	5850.61	5896.70	0.80
Three-Profile	**0.01**	**5754.12**	**5817.93**	**0.83**
Four-Profile	0.03	5749.99	5831.53	0.72
Five-Profile	0.01	5733.99	5833.26	0.75
Varying variance and covariance				
One-Profile	n/a	5731.46	5781.09	1
Two-Profile	0.02	5708.26	5811.07	0.94
Three-Profile	0.04	5695.85	5851.84	0.81
Four-Profile	0.46	5691.86	5901.03	0.84
Five-Profile	0.07	5671.08	5933.42	0.76

Note: BLRT = Bootstrap likelihood ratio test; AIC = Akaike information criterion; BIC: Bayesian information criterion (BIC). The optimal model based on indices of fit is bolded.

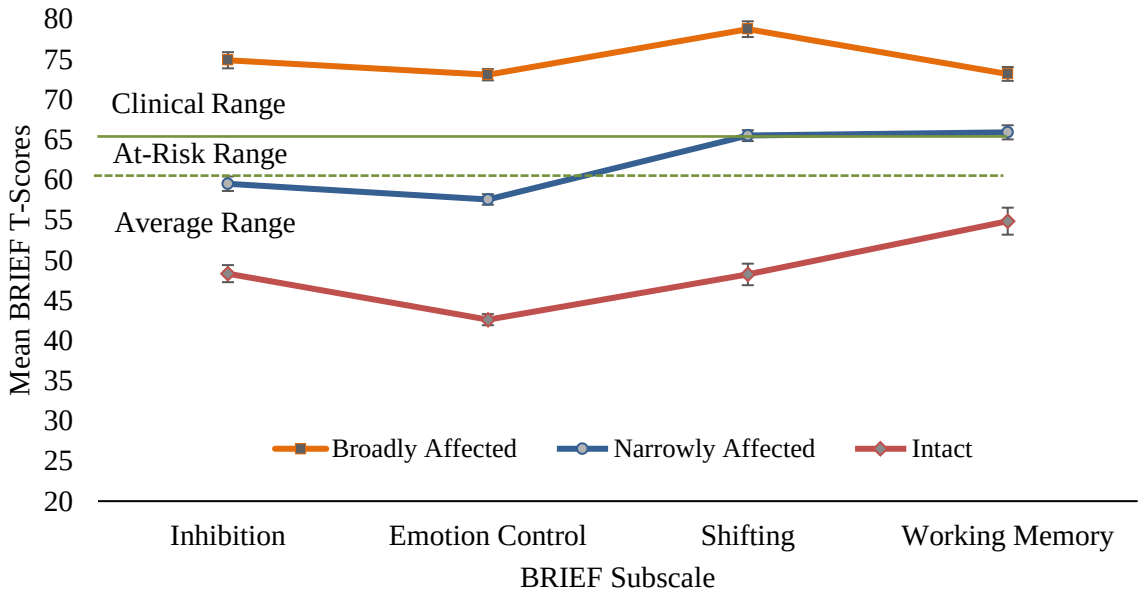
The first profile (*n* = 96) described 37.5% of the children in this sample and was labelled "*Broadly Affected Skills*". Children in this profile presented with clinically significant challenges in all core areas of EF and emotion control as reported by their caregiver. Average T-scores for the Inhibit, Working Memory, Shift, and Emotion Control subscale of the BRIEF were all significantly higher than those of Profile 2 and Profile 3 (Table 4), and all fell in the clinically significant range (Figure 2). Additionally, all children in this profile presented with Behavioural Regulation Index (BRI) scores in the clinically significant range, while 82% had Metacognition Index (MI) scores in the clinical range.

The second profile (*n* = 119) described 46.5% of the children in the sample and was labelled *"Narrowly Affected Skills".* Children in this profile were characterized as having challenges in some aspects of their core EF skills, but not in all domains. Specifically, on average, children with higher probability of belonging to this profile presented with clinically significant difficulties on the Shift and Working Memory subscales of the BRIEF, but below clinical range cut-off (described as "Average" range), as compared to other children of the same age and biological sex, on the Inhibit and Emotion Control subscales (Figure 2). Inhibition and emotion control skills, on average, were still higher in this profile than those of children in Profile 3. The majority of children in Profile 2 continued to present with BRI (68%) and MI (72%) scores in the clinically or at-risk range.

The last profile, which represents the smallest group (*n* = 41), described 16% of the children in the sample and was labelled *"Intact Skills"*. Children in this profile, on average, presented with core EF and emotion control skills in the "Average" range (Figure 2). None of the children with higher probability of belonging in this profile over the other two, presented with clinically significant challenges on the Inhibit or Emotion Control subscales of the BRIEF.

Meanwhile only 5% and 24% showed challenges in shifting and working memory, respectively. A small proportion of participants in this profile (n= 6; 15%) received MI scores in the clinical range, while none of the participants met this cut-off level for their BRI scores.

Figure 2. Mean T-Scores of BRIEF Subscales used to Construct the Profiles.



Differences Among Profiles

The mean and standard deviation of the BRIEF subscales and those of the clinical and demographic variables for each profile can be found in Table 4. Age and male to female ratio did not significantly differ among profiles (Table 4). After correcting for multiple comparisons, the FSIQ was the only cognitive skills measure that significantly differed among profiles (F (2,242) = 4.42, p = 0.013, η^2 = 0.035). Follow-up Tukey HSD post-hoc analyses, indicated that the "*Intact Skills*" group (M = 94.02, SD = 16.64) had on average a lower FSIQ compared to the "*Narrowly Affected*" group (M = 102.76, SD = 18.77). However, all three profiles had a mean FSIQ well within the average range, and thus, although this difference is statistically significant, it does not hold much clinical significance, especially with the small effect size (Table 4).

Table 4. Mean (SD) of BRIEF Subscales, ASD symptoms, Age, Cognitive Ability, Adaptive Skills, and Emotional/Behavioural Challenges Across the Three Profiles

	Broadly Affected (Profile 1)	**Narrowly Affected (Profile 2)**	**Intact (Profile 3)**	**F test**	**η_2**
n (% male)	96 (79%)	119 (78%)	41 (61%)	$\chi^2 = 5.86$ p = 0.053	
Age (months)	125.14 (31.93)	133.56 (37.36)	120.66 (28.70)	F(2,253) = 2.86, p = 0.059	
BRIEF (T-Scores)					
Inhibit	74.88 (9.84)	59.51 (9.83)	48.32 (6.80)	**F(2,253) = 133.90, p < 0.000**[abc]	0.514
Emotion Control	73.08 (6.90)	57.55 (7.16)	42.59 (4.42)	**F(2,253) = 326.60, p < 0.000**[abc]	0.721
Working Memory	73.18 (8.42)	65.91 (9.59)	54.85 (10.76)	**F(2,253) = 56.07, p < 0.000**[abc]	0.307
Shift	78.75 (9.58)	65.50 (7.40)	48.22 (8.59)	**F(2,253) = 194.50, p < 0.000**[abc]	0.606
Cognitive Skills					
Verbal IQ*	100.70 (15.96)	101.96 (20.25)	92.93 (14.83)	F(2,242) = 3.94, p = 0.021	
Nonverbal IQ*	104.20 (14.96)	103.40 (18.21)	96.93 (17.44)	F(2,242) = 2.83, p = 0.061	
Full Scale IQ*	102.36 (14.21)	102.76 (18.77)	94.02 (16.64)	**F(2,242) = 4.42, p = 0.013**[c]	0.035
CBCL					
Anxious*	65.00 (8.77)	58.68 (7.95)	55.57 (6.33)	**F(2,206) = 20.18, p < 0.000**[ab]	0.164
Aggressive*	65.94 (8.09)	55.82 (5.91)	51.21 (3.02)	**F(2,206) = 76.06, p < 0.000**[abc]	0.425
Attention*	72.04 (10.01)	64.21 (7.47)	59.68 (7.61)	**F(2,206) = 29.36, p < 0.000**[ab]	0.222
SRS-2					
SCI	75.94 (8.97)	71.30 (8.99)	62.40 (9.53)	**F(2,182) = 21.03, p < 0.000**[abc]	0.188
RRB	78.15 (11.38)	70.89 (11.25)	57.36 (8.93)	**F(2,182) = 33.54, p < 0.000**[abc]	0.269
Adaptive Skills					
ABC*	76.21 (12.65)	78.24 (11.82)	84.33 (10.59)	**F(2,209) = 4.68, p = 0.010**[a]	0.043
Communication*	81.42 (15.42)	82.02 (14.28)	85.85 (12.35)	F(2,208) = 0.98, p = 0.377	
Living Skills*	81.44 (15.47)	81.20 (12.67)	88.93 (10.32)	F(2,209) = 3.69, p = 0.027	
Socialization*	70.64 (11.30)	77.11 (13.03)	83.63 (13.30)	**F(2,209) = 13.17, p < 0.000**[ab]	0.112

Notes. *winsorized values. SCI: Social Communication Impairment index; RRB: Repetitive, Restricted Behaviour index.
Post-hoc tests ($p < 0.017$): [a]comparing Profile 1 and Profile 2; [b] Profile 1 and Profile 3; [c] Profile 2 and Profile 3.

As reported above, all profiles significantly differed from each other on inhibition, emotion control, shifting, and working memory skills, with individuals in the "*Broadly Affected*" profile showing the most difficulties, and children in the "*Intact*" profile showing the least. Of the four core EF, differences in scores on the Emotion Control subscale of the BRIEF accounted for the biggest variance among profiles ($\eta^2 = 0.72$), while Working Memory differences accounted for the least ($\eta^2 = 0.31$) (view Figure 2 for a visual representation).

With regards to emotion and behavioural challenges, the one-way ANOVAs indicated clinically significant difference among profiles with regards to caregiver reports on the three syndrome scales of the CBCL (Table 4). Post-hoc analyses revealed that children in the "*Broadly Affected*" profile, on average, have more elevated levels of anxiety, attention problems, and aggressive behaviours compared to children in other two profiles. Children in the "*Narrowly Affected"* and "*Intact"* profiles only differed with regards to reported level of aggressive behaviours, with children in the "*Narrowly Affected*" group (M = 55.82, SD = 5.91) showing more challenges in this area than children in the "*Intact*" group (M = 51.21, SD = 3.02). In the "*Broadly Affected"* profile, 26% of children presented with scores in the clinical range for anxiety problems, 46% for attention challenges, and 25% for aggressive behaviours. Meanwhile no children in the other two profiles, fell in the clinical range for aggressive behaviour concerns, with no children in the "*Intact"* profile having reported challenges in anxiety.

One-way ANOVA results also indicated significant difference in the SRS-2 across all profiles (Table 4), with children in the "*Broadly Affected"* profile showing more elevated levels of ASD symptoms in regard to both social communication impairment (SCI) and repetitive patterns of behaviours (RRB), followed by children in the "*Narrowly Affected*" profile, and then those in the "*Intact"* profile. Additionally, children in the "*Broadly Affected"* profile had

significantly more delays in adaptive skills in the domain of socialization as assessed by the VABS (M = 70.64, SD = 11.30), compared to children in the other two profiles, who did not significantly differ from each other (Table 4). Significant differences among profiles with regards to overall adaptive skills were also observed (F (2,209) = 4.68, p = 0.010), but the effect size was very small ($\eta^2 = 0.043$). Overall, children in the "*Broadly Affected*" profile, on average, presented with more elevated ASD symptoms, greater challenges in anxiety, attention, and aggression, and more delayed adaptive skills, compare to children in the "*Intact*" profile, and at times also compared to children in the "*Narrowly Affected*" profile.

Predicting Profile Membership

Multinomial logistic regressions were used to determine which variables could predict profile membership. Results indicated that gender, level of aggressive behaviour, and ASD symptom severity significantly predicted group membership (see Table 5). More specifically, being male was associated with greater odds of being in the "*Broadly Affected*" profile rather than the "*Intact*" one. Additionally, for every one unit increase on the RRB scale of the SRS-2, the odds of children belonging to the *"Broadly Affected"* profile versus *"Narrowly Affected"* or *"Intact"* profiles were increased by 1.13 and 1.09, respectively. With regards to social communication difficulties, a one unit increase on the SCI scale of the SRS-2 multiplied the odds of being in the "*Broadly Affected*" profile rather than the "*Intact*" profile by 1.11. The SCI was not predictive of difference between the *"Narrowly Affected"* and the "*Intact"* profiles. Lastly, a one unit increase on the CBCL-aggressive syndrome scale was associated with 1.44 greater odds of being in the "*Broadly Affected"* profile rather than the *"Intact"* one, 1.23 greater odds of being in the "*Narrowly Affected"* profile rather the *"Intact"* one, and 1.17 greater odds of being in the "*Broadly Affected"* profile than the "*Narrowly Affected"* one. Together, these results

indicate that the more challenges a child with ASD has on EF and emotion control skills, the greater the odds that they will also have reported challenges in aggressive behaviours, and present with more severe ASD symptoms. Age, adaptive skills, cognitive abilities, and challenges in anxiety and attention were all not significantly predictive of group membership (see Table 5).

Table 5. Multinomial Logistic Regression Analysis of Profile Membership

Profile	Predictors	β (SE)	Wald's test	*p*	Odds ratio
*Broadly vs Intact**	**Biological Sex**	**1.81 (.87)**	**2.07**	**0.038**	**6.10**
	Age	0.01 (.01)	1.36	0.173	
	FSIQ	0.03 (.02)	1.38	0.168	
	CBCL- Anxiety	0.01 (.06)	0.22	0.823	
	CBCL- Aggressive	**0.36 (.08)**	**4.70**	**0.000**	**1.44**
	CBCL- Attention	0.06 (.06)	0.99	0.324	
	SRS-2- SCI	**0.11 (.05)**	**2.15**	**0.032**	**1.11**
	SRS-2- RRB	**0.12 (.05)**	**2.26**	**0.024**	**1.13**
	VABS- Socialization	0.02 (.03)	0.61	0.541	
*Narrowly vs Intact**	Biological Sex	1.22 (.73)	1.68	0.092	
	Age	0.01 (.01)	1.71	0.087	
	FSIQ	0.02 (.02)	1.27	0.203	
	CBCL- Anxiety	-0.01 (.05)	-0.18	0.857	
	CBCL- Aggressive	**0.21 (.07)**	**2.78**	**0.000**	**1.23**
	CBCL- Attention	0.03 (.06)	0.48	0.631	
	SRS-2- SCI	0.08 (.04)	1.92	0.055	
	SRS-2- RRB	**0.09 (.05)**	**2.03**	**0.042**	**1.09**
	VABS- Socialization	0.04 (.02)	1.49	0.136	
*Broadly vs Narrowly**	Biological Sex	0.58 (.56)	1.05	0.295	
	Age	0.00 (.01)	-0.05	0.963	
	FSIQ	0.01 (.01)	0.46	0.648	
	CBCL- Anxiety	0.02 (.03)	0.74	0.457	
	CBCL- Aggressive	**0.16 (.04)**	**4.20**	**0.000**	**1.17**
	CBCL- Attention	0.03 (.03)	1.07	0.283	
	SRS-2- SCI	0.03 (.03)	0.74	0.457	
	SRS-2- RRB	0.02 (.03)	0.89	0.371	
	VABS- Socialization	-0.02 (.03)	-0.61	0.542	

Note. * indicate which profile was used as the reference group. Bolded values indicate significant results at $p < 0.05$. Only odds ratio for signficant variables are reported.

Discussion

Despite the accepted view that most individuals with ASD present with challenges in at least some aspects of emotion regulation and executive functioning, there remains a poor understanding of the degree of those impairments across and within children with ASD. Thus, the primary aim of the current study was to gain a better understanding of the heterogeneity of core EF and emotion control skills in children with ASD by using a person-centered approach. Using a latent profile analysis, three distinct profiles were identified using a sample of children with ASD between the ages of 6 to 18 years old: (1) "*Broadly Affected*" profile; (2) "*Narrowly Affected*" profile; and (3) "*Intact*" profile. The three identified profiles showed significant differences across inhibition, emotion control, shifting, and working memory skills, as measured by caregiver ratings on the BRIEF. One profile was characterized by clinically significant deficits on all four subscales of interest ("*Broadly Affected*"). One profile only showed impairments in working memory and shifting skills but intact emotion control and inhibition skills ("*Narrowly Affected*"). Lastly, the third profile was characterized by no significant impairments in all four subdomains of the BRIEF ("*Intact*"). Together, these results provide support for the growing view that individuals with ASD present with heterogeneous EF and emotion control abilities, ranging from impaired to well developed skills (e.g., Baez et al., 2020; Dajani et al., 2016; Pellicano, 2012). Additionally, given the presence of a subgroup of children with ASD with intact EF skills, the results of the current study provide evidence against the theory of broad executive dysfunction in ASD (e.g., Demetriou et al., 2018; Hughes et al., 1994; Ozonoff et al., 1991), and support the notion that EF skills vary greatly in ASD.

The three identified profiles in the current study differ slightly from previous research that used a similar analytical method with samples of children with ASD. Both Baez and

colleagues (2020) and Dajani and colleagues (2016) also identified three profiles, but two of these subgroups had either average or above average subdomain scores on the BRIEF, while the last group presented with impairments across all subdomains measured. These differences across the current study and previous studies are likely a result of differences in samples used. The current study used a purely ASD sample to conduct the latent profile analyses, while previous studies used mixed samples that included typically developing children (Baez et al., 2020) and children with a broader range of neurodevelopmental disorders (Dajani et al., 2016). Including TD children in the sample likely attenuated the variability in the ASD group, and thus the results from Dajani and Baez studies are more a representation of EF profiles in the broader population rather than in ASD. Across both previous studies, children with ASD were more prominent in the "impaired" group and only made up a small proportion of the "above average" and "average" groups. For example, in Baez and colleagues' study (2020), children with ASD had a higher probability of belonging to the "impaired" (0.93), compared to TD children (0.07), meanwhile TD children had higher probabilities of belonging to the "above average" (0.96) or "average" (0.71) group compared to children with ASD (probability = 0.04 and 0.29, respectively). Using a purely ASD sample, the current study was able to examine more deeply the "impaired" profile that previous studies identified and to tease it apart into two subgroups: "*Broadly Affected*" and "*Narrowly Affected*".

A second important difference between the current study and the work of Dajani and Baez is that profiles here were derived using different subdomains of the BRIEF, with previous studies using a broader range of EF skills (Baez et al., 2020; Dajani et al., 2016). In the current study the focus was primarily on the three core EF skills as described by Miyake's model, with the addition of emotion control. Focusing on only four functions, instead of looking at all 8

BRIEF subdomains, might have allowed for a more in-depth analysis of how these four functions vary with each other. For example, the *"Narrowly Affected"* profile was characterized with some skills as intact and some as impaired, demonstrating that not all skills need to follow the same pattern (e.g., all impaired or all intact). Meanwhile, in both Dajani et al. (2016) and Baez et al. (2020) studies, all individual EF functions measured varied in a similar fashion, which is more consistent with patterns seen in TD children.

Predictors of Profile Membership

In addition to presenting with different levels of EF and emotion control abilities, the three profiles also differed based on symptoms associated with ASD and emotion and behavioural challenges. For example, children with a higher probability of belonging to the "*Broadly Affected*" profile presented with higher levels of reported ASD symptoms and greater challenges in anxiety, attention, and aggression, compared to the children in the other two profiles. Of these variables, level of aggressive behaviour and repetitive patterns of behaviours and interests (RRBs) were found to be predictive of group membership. The general pattern indicated that the odds of belonging to the "*Broadly Affected*" profile compared to the other two groups, increased as reported level of aggressive and repetitive and restricted behaviors increased. This is consistent with previous research which has demonstrated a close relationship between SRS ratings and externalizing behaviour (see Hus et al., 2013 for more information). Furthermore, by looking at predictive patterns of profile membership, such as which variable significantly predicts group membership across which combination of profile (*"Broadly Affected"* vs "*Narrowly Affected"*, *"Narrowly Affected"* vs "*Intact*", or *"Broadly Affected"* vs "*Intact*"), more information can be gathered regarding the link between these variables and EF and emotion control skills in ASD. For example, a higher reported presence of RRBs increased

the odds of belonging to the *"Broadly Affected"* or the *"Narrowly Affected"* profile versus the *"Intact"* profile, but not in belonging to the *"Broadly Affected"* versus the *"Narrowly Affected"*. Given that challenges in shifting and working memory are what primarily differentiates the "*Intact*" group from the other two, it is possible that these two core EF skills may be inversely associated with RRBs. Challenge in shifting, which can represent a measure of cognitive flexibility, is one of the most consistently reported EF deficit in children with ASD (e.g.,Garon et al., 2018; Geurts et al., 2004; Gioia et al., 2002a; Kenworthy et al., 2008; Ozonoff & Jensen, 1999) and many have hypothesized that challenges in cognitive flexibility are directly contributing to the behavioural rigidity seen in individuals with ASD (D'Cruz et al., 2013; Faja & Nelson Darling, 2019; Miller et al., 2015; Shafritz et al., 2008; Yerys et al., 2009). Less research examining the link between working memory and ASD symptoms exists, although in a review of the literature, Kercood and colleagues (2014) found that lower verbal working memory was linked to greater RRBs.

Meanwhile, the predictive patterns of group membership seem to indicate that higher levels of aggressions are linked to broader EF and emotion control challenges as the odds of belonging to a profile with more challenges compared to one with less increased with each increase in reported aggression. These results are consistent with previous research which has shown that EF and emotion control skills can be predictive of aggressive behaviours in children with ASD, especially shifting (Lawson et al., 2015; Sullivan et al., 2019; Visser et al., 2014) and inhibition and emotion control (Gardiner & Iarocci, 2018; Raaijmakers et al., 2008; Vogan et al., 2018). Some have even postulated that EF challenges may serve as a pathway from which behavioural and emotional challenges, such as aggression and anxiety, develop in children with ASD, especially due to the close link between EF and self-regulation (Lawson et al., 2015;

Visser et al., 2014). For example, challenges in shifting may lead to higher levels of rumination, and difficulties in adapting behaviours to changing settings resulting in frustration and outbursts, or anxiety (e.g., Lawrence et al., 2006). However, it is important to note that only a quarter of participants in the current sample presented with clinically significant challenges in aggression, and thus it is critical to interpret the current results with caution. Additionally, research has also demonstrated that higher rates of repetitive patterns of behaviours in children with ASD were associated with higher levels of reported aggressive behaviours (Sullivan et al., 2019). Therefore, there might be an interaction among core EF skills, ASD symptoms, and aggression that is at play here, but this was beyond the scope of the current study. Future research, especially longitudinal studies looking at the relationship between the concurrent development of EF and emotion control skills and aggression in children with ASD, is required to gain a better understanding of these challenges and their interactions.

Another significant predictor of group membership was biological sex. Despite the fact that profiles did not significantly differ with regards to the male to female ratio, being male increased the odds of belonging to the "*Broadly Affected*" profile compared to the "*Intact*" profile by more than six times. These results stand in contrast to the existing literature on biological sex and EF skills in children with ASD as the majority of studies seem to indicate that females have more challenges with EF than males (Lemon et al., 2011; Nydén et al., 2000; White et al., 2017). However, one study found that in a sample of individuals with ASD, females outperformed male participants on a performance task measuring shifting and inhibition (i.e., Trail-Making Test) and that this was correlated with fewer RRB symptoms (Bölte et al., 2011). Additionally, several studies have shown that females with ASD tend to present with fewer RRB symptoms compare to their male counterparts (Bölte et al., 2011; Mandy et al., 2012; Park et al.,

2012; for review see Kirkovski et al., 2013). It is possible that again there is an interesting interaction among core EF and emotion control skills, RRBs, and biological sex that may explain the current findings. However, it is important to note that the current study relied on raw scores of the BRIEF to run the latent profile analysis. Raw scores are not adjusted for age or gender. When the analysis was re-run with T-scores of the BRIEF, although the same three profiles emerged, biological sex was no longer predictive of group membership. Therefore, it is possible that this effect is a simple result of general differences in everyday EF and self-regulation skills across biological sex (Gioia et al., 2000a).

Cognitive abilities, adaptive skills, and age were not predictors of group membership. However, some profiles did differ from each other based on mean adaptive skills and overall cognitive abilities, but these only account for a very small amount of the variance among groups. Meanwhile, the average age of participants in the three profiles did not significantly differ from each other despite using raw subdomain scores of the BRIEF. Additionally, preliminary analyses indicated that age of participants was only significantly predictive of total raw inhibition score on the BRIEF, but not for the other three subscales. Together, these results seem to indicate that age may not be as strong a factor for core EF and emotion control abilities in children with ASD compared to TD peers when using informant-based measures. This may partially be a result of the heterogeneous presentation of children with ASD and the wide range of neurobiological differences in this population (see O'Hearn et al., 2008, for review). More specifically, given these differences, it is conceivable that children with ASD may present with varying trajectories with regards to the development of their EF and emotion control skills. For example, some children may follow the same developmental pattern as typically developing peers, while others may have a delayed and protracted development, and yet others may have completely different

trajectories. Research in the field of EF development in children with ASD has shown these different types of patterns across studies (Luna et al., 2007; O'Hearn et al., 2008). For example, younger children with ASD have been shown to have EF skills comparable to typically developing peers on performance-based measures (e.g., Dawson et al., 2002; Griffith et al., 1999; Yerys et al., 2007), as well as on informant-based measures (e.g., Carotenuto et al., 2019). Meanwhile, Happé and colleagues (2006) found age related improvement in EF performance-based tasks in children with ASD, where participants with ASD performed below same age peers during childhood, but then showed comparable performance during teenage years, demonstrating a delay in EF development during childhood but then a rapid growth during adolescence. Researchers using informant-based measures have also found difference in levels of EF impairments in children with ASD based on age and executive function (e.g., van den Berg et al., 2014). Yet again, other studies using informant-based measures have shown a truncated EF development in individuals with ASD, with challenges becoming more apparent during late teenage years and adulthood, or for individuals with ASD who showed no improvement with age (Rosenthal et al., 2013; Vogan et al., 2018). These varying developmental trajectories in EF in children with ASD may make it more difficult to observe a clear link between EF skills and age in this neurodiverse group.

Limitations

The current study is not without limitations. First, most measures used in the current study rely on caregiver report, which may introduce a certain degree of rater bias. Secondly, the current study was limited to the properties of the measure used to collect EF and emotion control data. Although the BRIEF is a commonly used measure with evidence for its validity and reliability, using only one measure limits the generalizability of the current results. Specifically,

the profiles were constructed using an informant-based measure of executive and regulation functions, and although thought to be a more ecologically valid measure of everyday EF skills (e.g., Kenworthy et al., 2008), similar profiles may not emerge if performance-based measures are used. Over the years, little correlation between informant-based and performance-based measures of EF has been found which has led many to conclude that performance- and informant-based tools measure different but complementary aspects of executive functions (e.g., Ten Eycke & Dewey, 2016; Toplak et al., 2013). Future research might want to investigate whether the results of the current study can generalize to performance-based measures of EF (and emotion control) as this could provide further evidence for the robustness of these profiles in children with ASD.

Thirdly, this is a cross-sectional study and therefore the potential effect of age and development across the different profiles in children with ASD could not be directly evaluated. Although no differences in mean age were found among the three groups, it was impossible to determine whether the profiles may vary at different points during development, especially given the broader age range of participants included in the current study. Future studies might want to explore whether the same profiles emerge across distinct age groups of children with ASD (e.g., preschoolers versus school age versus teenagers) to gain a better understanding of the impact of brain development and maturation on these profiles. Ideally, longitudinal studies that integrate person-centered and variable-centered approaches, such as growth mixture models (Grimm et al., 2017), could provide important information on whether different developmental trajectories of executive function and emotion control exist in children with ASD.

Clinical Implications and Conclusion

Given the important role that EF and emotion control play in daily functioning and life outcome, gaining a better understanding of the heterogeneity of these skills in children with ASD is critical and can be useful in informing programming and intervention for these individuals. The results of the current study indicate that there are three subgroups of children with ASD with varying profiles of core executive functions and emotion regulation. Information from these profiles can help guide decisions around how to develop targeted treatment for this neurodiverse group. For example, challenges in inhibition and emotion control skills are associated with a broader profile of affected executive and regulation skills and this profile on average represents children with more severe ASD symptoms and higher levels of co-occurring behavioural and emotional challenges. Given this, it is possible that treatment programs aiming at supporting the development of inhibition and emotion control in children with ASD may be more advantageous for children with more severe presentation of ASD and co-occurring mental health challenges.

Results of the current study also indicates that not all children with ASD need EF and emotion control interventions. It is important to assess the individual profile of strengths and challenges in areas of everyday executive and regulation skills of the child before entering them in an intervention. This is especially important for EF interventions as research has shown that the most promising EF programs for children are those in which children feel continuously challenged in the task they are performing (Holmes et al., 2009; Klingberg et al., 2005) and where the limit of their abilities are continuously being tested (e.g., Davis et al., 2011; Diamond et al., 2007; see Diamond, 2012 for review). Therefore, taking a person-centered approach when working with this population is extremely important. It is hoped that the information presented in

the current study can be used as a steppingstone to inform program development and research in EF and emotion regulation training programs specific to this clinical group.

Chapter 3: Inhibition and Emotion Regulation Training Programs for Children with Autism Spectrum Disorder: A Systematic Literature Review

The ability to ignore external and internal distractors, to interrupt or stop an ongoing or prepotent response, and to control motor activities, attention, and behaviours, are all aspects of the multifaceted construct of inhibition (Friedman & Miyake, 2004). To effectively interact and learn from the environment and people around them, children must develop inhibition skills. For example, children must use their inhibition skills when listening to directives from a teacher or their parents in order to ignore distractors and remain focused on the task at hand. Additionally, inhibition plays a central role in the development of other executive functions (Barkley, 1996; Dempster, 1993; Diamond, 2013; Miyake et al., 2000), and is required for the development of self-regulation, especially the aspects of emotion and behaviour regulation (e.g., Diamond, 2002; Jahromi et al., 2013; Kochanska et al., 1998; Mazefsky et al., 2013; Stifter et al., 1999; Thompson, 1994; Zelazo & Cunningham, 2007). Delays in the development of inhibition can have significant repercussions on children's cognitive (e.g., Diamond, 2000), academic (e.g., Blair & Diamond, 2008; Blair & Razza, 2007; Bull et al., 2008; Fuhs et al., 2014; McClelland et al., 2007; Raver et al., 2011), and social (e.g., Durlak et al., 2011; Eisenberg et al., 1995; Fuhs et al., 2014) abilities, and has been linked to worse health outcomes, higher rates of crime (Moffitt et al., 2011), and more externalizing behaviour problems (e.g., Livesey et al., 2006; White et al., 2013). Challenges in inhibition skills are also more common in children with neurodevelopmental disorders, such as autism spectrum disorder, compared to typically developing peers (for review see Geurts et al., 2004). Given the importance of inhibition on children's development and life outcome, programs intended to teach inhibition skills, either at a discrete level (e.g., cognitive training of inhibition skill) or within the broad concept of self-

regulation (e.g., emotion regulation programs or behavioural regulation training programs), have exponentially increased over the last few years. Gaining a better understanding of what programs exist and the evidence behind them is essential for effectively supporting the development of children, especially those with identified difficulties in inhibition and self-regulation, such as children with ASD.

Links Among Inhibition, Emotion Regulation, and Self-Regulation

The following section briefly recaps the framework in which the current manuscript operates, for more details refer to Chapter 1. Inhibition falls under the broad umbrella term of executive functioning (EF) and is seen as a core executive function that is essential for the development of other more complex skills, such as problem solving, goal planning, and organizing (Barkley, 1996; Dempster, 1993; Diamond, 2013; Miyake et al 2000). Some have even argued that challenges in all other aspects of executive function stem from difficulties in inhibition, especially resistance to interference (e.g., Barkley, 1996, 1997; Dempster, 1993). Meanwhile, self-regulation (SR) is another broad construct that refers to top-down processes involved in the goal directed behaviours aimed at achieving control over one's own actions, thoughts, and emotions (Blair & Diamond, 2008; Kopp, 1982; Shapiro et al., 2015; Zelazo & Lyons, 2012). In the literature, self-regulation is at times broken down into multiple subcomponents, such as emotion regulation and behaviour regulation. Emotion regulation refers to the subdomain of self-regulation involved in adaptively monitoring and modulating the intensity, duration, and expression of one's emotions to effectively pursue a goal (Cole et al., 1994; Eisenberg & Spinrad, 2004; Thompson, 1994). Looking at emotion regulation in isolation can be challenging due to high degrees of overlap among the other subcomponents of self-regulation. For example, in cases where the goal of regulating emotions is to prevent physical

outbursts, then emotion regulation becomes synonymous with self-regulation as the goal targets multiple subcomponents (i.e., behaviour and emotion regulation, and potentially cognitive control). This illustrates how easily these constructs may overlap and why they at times are used interchangeably in the literature. Within the current framework, emotion regulation is seen as a required component of self-regulation, and thus if an individual engages in emotion regulation, they are self-regulating. Meanwhile, self-regulation does not necessarily imply regulation of emotions as it can exist outside of emotions, such as regulating one's attention and eye gaze to remain focus on someone presenting.

Despite the fact that EF and SR are viewed as distinct but related top-down processes that can be studied separately, in the real world they often occur together. When EF and SR show the most overlap, inhibition skill is often at the center. Inhibition skills have been considered a key mechanism for the proper development of emotion and behaviour control, and thus self-regulation skills in general (e.g., Diamond, 2002; Jahromi & Stifter, 2008; Jahromi et al., 2013; Kochanska et al., 1998; Stifter et al., 1999; Thompson, 1994; Zelazo & Cunningham, 2007). For example, if a child's goal is to make friends, they may eventually come to learn that being considered a "good sport" when losing a game is important. In this situation, children must quickly learn that they need to inhibit negative states and affect, and control their external behaviours in order to not be judged negatively by peers. More specifically, children may need to inhibit their urge to storm out or yell at their opponent, which requires them to successfully regulate the negative emotion that may come from losing the game, while also modulating their actions. If children consistently fail to use their inhibition and SR skills, especially emotion regulation, in social situations, they will struggle to develop and maintain meaningful relationships with others (e.g., Eisenberg et al., 1995; Miller et al., 2004; Rawn & Vohs, 2006).

Assisting children in developing their inhibition and emotion regulation skills becomes especially important in the development of children with known difficulties in social skills such as children with ASD (Hill, 2004; Kenworthy et al., 2008; Loveland, 2005; Pennington & Ozonoff, 1996; Prizant et al., 2003).

Inhibition and Emotion Regulation in ASD

Although not recognized as core symptoms of ASD, challenges in inhibition (and other EF) and emotion regulation (and SR more broadly) are frequently observed in children with ASD (for reviews see Cibralic et al., 2019; Geurts et al., 2014; Hill, 2004; Jahromi, 2017; Kenworthy et al., 2008; Mazefsky et al., 2013). Challenges in these top-down processes have been shown to be linked to more severe ASD symptoms (e.g., Samson et al., 2014; Van Eylen et al., 2015) and to be predictive of treatment outcomes for individual with ASD (e.g., Berkovits et al., 2017; Bishop-Fitzpatrick et al., 2016; Friedman & Sterling, 2019; Gardiner & Iarocci, 2018; Pellicano et al., 2017; Pugliese et al., 2016; Tajik-Parvinchi et al., 2020). Inhibition and emotion regulation skills have repeatedly been linked to each other in children with ASD (e.g., Jahromi et al., 2013; Mazefsky & White, 2014). This statement is further supported by the results of the study presented in Chapter 2, as inhibition and emotion control skills across the three ASD profiles always varied in a similar fashion (e.g., both within the clinical range or well outside of it).

In their model on emotion dysregulation in children with ASD, Mazefsky and White (2014) specifically identify inhibition as one of the potential contributors, stating that impairment in inhibition likely interferes with the activation of proper emotion regulation strategies and the ability to inhibit automatic responses. This perspective is consistent with other psychological models in the typically developing (TD) literature that have postulated that inhibition skills can directly impact one's ability to engage in emotion regulation skills, such as limiting rumination,

controlling motor impulses, and stopping unhelpful thoughts (e.g., Hwang et al., 2016; Joormann, 2010; Joormann & Gotlib, 2010; Leen-Feldner et al., 2004; Penela et al., 2015; Suarez et al., 2021). Challenges in emotion regulation and inhibition can take many forms, including increased levels of irritability and tantrums, aggression, mood dysregulation, noncompliance, and anxiety. These behaviours have all been regularly documented in children with ASD (e.g., Lecavalier et al., 2019, Prizant & Laurent, 2011; Quek et al., 2012), and are known to impact development, overall functioning, and long-term outcomes (e.g., Holden & Gitlesen, 2006; Matson & Nebel-Schwalm, 2007), along with the quality of life of caregivers (see Vasilopoulou & Nisbet, 2016 for review). Furthermore, emotion regulation and inhibition difficulties have also been linked to other disorders such as anxiety, depression, and conduct disorder (e.g., White et al., 2013), putting individuals with ASD at risk of comorbid diagnosis. This hypothesis is in line with the high prevalence rate of children with ASD who also present with co-occurring internalizing and externalizing disorders, such as emotional difficulties and disruptive behaviors (view Totsika et al., 2011 for review). Together, these studies demonstrate the negative impact that inhibition and emotion regulation (and ultimately self-regulation) challenges can have on the development of children with ASD and the importance of fostering the development of these core skills.

Inhibition and Emotion Regulation Interventions for ASD

Given the broad ranging repercussions of inhibition and emotion regulation challenges, it follows that programs specifically targeting these areas of needs are being developed. Over the past few years, a wide variety of interventions have been put forward to support the development of different aspects of inhibition (e.g., Macoun et al., 2020), emotion regulation (e.g., Weiss et al., 2018), and self-regulation more broadly in children with ASD (e.g., Nowell et al., 2019).

These programs vary considerably with regards to their theoretical foundation, methods of delivery, the professionals who are advocating for these interventions (i.e., behavioural therapists, occupational therapists, psychologists, medical doctors, etc.), and the empirical evidence supporting them. This broad range of interventions makes it difficult for families, clinicians, and researchers to know what is out there and what is best suited for children with ASD. Therefore, a thorough systematic review of the literature to identify pre-existing programs and interventions targeting inhibition and emotion regulation skills in children with ASD could be extremely beneficial.

Several systematic reviews of interventions for individuals with ASD have been published (e.g., Bourgeois et al., 2019; Dandil et al., 2020; Semple, 2019). However, these reviews often look at the effects of one specific type of intervention (e.g., cognitive remediation/training) on a broad range of outcomes (e.g., Dandil et al., 2020; Semple, 2019). For example, Semple (2019) looked at the effect of yoga and mindfulness-based interventions for youth with ASD. Of the eight studies that met inclusion criteria, the main outcome measures varied enormously from improvements in communication, motor control, social abilities, behavioural symptoms, and reduction in irritability (Semple, 2019). These types of systematic reviews, although important for the field, provide limited information regarding what components of an intervention may facilitate improvement in a targeted domain (e.g., Do mindfulness-based intervention for youth with ASD help improve inhibition skills?). Meanwhile, there are some systematic reviews that have looked at interventions targeting the training of specific skills in ASD, but these often include EF more broadly (e.g., Bourgeois et al., 2019; Pasqualotto et al., 2021) and/or include a broader range of neurodevelopmental disorders (e.g., Sung et al., 2022; Varigonda et al., 2021). To date, no systematic review looking at

interventions across a broad range of treatment methods and focusing specifically on training inhibition and/or emotion regulation skills in children with ASD exist. Given the close link between inhibition and emotion regulation skills, having one review that combines information on training programs that target either or both of these skills could provide more insight into our broader understanding of emotion regulation and inhibition and how targeted interventions in these areas could help support children with ASD.

Current Review

The current review aimed to provide a systematic overview of what types of training programs targeting inhibition and emotion regulation skills in children with ASD exist, and to identify key components of these programs. Specifically, the following questions were examined: a) what programs designed to improve inhibition and emotion regulation skills in children with ASD exist, b) what is the evidence behind these programs, and c) what common features can be identified across programs demonstrating promising results. It is hoped that the information collected and summarized in this systematic review can support the development and refinement of these intervention programs, which in turn has the potential of impacting the outcome and trajectory of children with ASD.

Methods

This review was registered with the International Prospective Register of Systematic Reviews (PROSPERO; registration number: CRD42021243700). Procedures and reporting were performed following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009).

Literature Searches

Five databases were systematically searched to locate articles: Medline, PsycINFO, EMBASE, ProQuest, and Educational Resources Information Center (ERIC). Grey literature searches, snowball searches of eligible studies, and manual searches of three autism focused journals (i.e., Autism, Journal of Autism and Developmental Disorders, and Research in Developmental Disabilities) were also performed to identify as many relevant studies as possible. Searches were conducted between June 2nd and June 16th, 2021 and were limited to peer-reviewed journal articles that were published in English or French between 1987 and 2021. Articles published prior to 1987 were excluded as the ASD diagnostic criteria prior to the publication of the revised version of the Diagnostic and Statistical Manual of Mental Disorders, third edition (DSM III-R), in 1987, were too broad and may have included developmental disabilities that would not today fall under the ASD diagnosis (Masi et al., 2017; Rosen et al., 2021).

Search Terms

A search strategy was developed using Siddaway and colleagues' (2019) best practice guide to conduct reviews, and in consultation with a librarian with expertise in systematic reviews and health studies. The original search strategy was first tested in Medline using the identified subject headings and keywords (see Supplemental Table 3 in Appendix B). The search strategy was then adapted to fit each of the other four databases individually. The search terms used fell under four general categories: a) autism spectrum disorder, b) children (age 0 to 17 years old), c) targeted skill being trained (i.e., inhibition and emotion regulation), and d) intervention. Two of these categories were in reference to the targeted population (i.e., children with ASD), one was in reference to the type of studies (i.e., interventions and training programs),

and one was in reference to the skills of interest (i.e., inhibition and emotion regulation). To determine whether an intervention was successful at training inhibition and/or emotion regulation skills, these skills needed to be measured pre and post intervention to show whether gains were made and therefore, inhibition and emotion regulation were also outcomes of interest. Given that inhibition falls under the umbrella term for EF, and several other executive functions require inhibition (e.g., switching requires one to stop an ongoing response to engage in a new one), the search category for targeted skill being trained was expanded to also incorporate "executive functioning" more generally, allowing for a broader search. Similarly, since emotion regulation is a subcomponent of SR, "self-regulation" was also included to cast a wider net. Search terms within each category and variations of these general terms, in addition to plural forms and United States and United Kingdom spellings, were also included in the search. Search terms belonging to the same category were grouped using the Boolean "OR" search operator and the four categories were then combined using the "AND" function (view Supplemental Table 3 in Appendix B). Together, these searches specifically looked for studies evaluating intervention programs aimed at training inhibition and/or emotion regulation skills in children with ASD below the age of 18.

Study Selection

All identified articles from the database searches and other searches (i.e., grey literature searches and manual searches) were transferred and assessed in Covidence, a systematic review software for article screening and data extraction. After removing duplicates, the articles were screened by two independent reviewers (M.F. and T.V.) for eligibility based on abstracts and titles. Following this initial screening stage, the articles that made it through to the next step were then further assessed based on full text review by both reviewers independently. Reviewers

agreed on 92% of the articles, and any discrepancies between the two reviewers were resolved through discussions, resulting in a 100% agreement on the final eligible articles. Figure 3 contains the PRISMA flowchart which illustrate the selection process, the number of articles reviewed at each step, and the reasons for exclusion in the later stages.

Inclusion and Exclusion Criteria

To be included in the review, articles needed to be peer-reviewed articles evaluating training programs targeting inhibition or emotion regulation skills in children with ASD. Additionally, the following inclusion criteria needed to be met: (1) components of the intervention were described, (2) the program was developed with the purpose of specifically teaching and training inhibition and/or emotion regulation skills, (3) pre and post measures of outcome of interest (i.e., inhibition and/or emotion regulation skills) were included in order to assess the effects of the intervention, (4) the study contained at least one group of children with a confirmed diagnosis of ASD, (5) full text was available in English or French, and (6) participants age ranged between 0 and 17 years of age. Given that inhibition and emotion regulation skills are greatly influenced by development, studies with participants who exceeded 17 years of age were excluded to minimize the potential confounding effects that older participants may have on the outcomes of the intervention, unless results from older participants were reported in isolation. All ranges of autism severity were accepted, but each study needed to have information on how an ASD diagnosis was confirmed in order to be included (e.g., use of ASD diagnostic tools or confirmation through verification of previous psychological assessments). No restrictions based on the design of the intervention (e.g., single-case design or group design), and on the size of the sample were made to include as many programs as possible.

Lastly, studies were excluded from the review if: (1) they did not include original research and data (i.e., reviews, editorial, secondary analyses of the same dataset), (2) no quantitative data were reported, (3) the interventions included biomedical or physical procedures such as psychotropic medication, dietary intervention, massage therapy, and transcranial stimulation, and (4) the intervention simply focused on decreasing challenging behaviours without including a teaching component to the participants (i.e., strictly conditioning behavioural procedures). It was important that the intervention explicitly attempted to make children with ASD aware of the skill being targeted and assist them in consciously making progress towards this behaviour as agents of change. Thus, simply blocking a behaviour and then redirecting the children's attention elsewhere, or providing the child with medication, would not be a sufficient treatment to be included in the current systematic review. The reasoning behind this is that research with children and adolescents has demonstrated that interventions in general, including those aimed at developing EF, are more successful when employing methods that provide an individual with direct instructions that explain the usefulness and purpose behind the skills being learned (i.e., using metacognition) (e.g., Dawson & Guare, 2014; Deshler et al., 1996; Hume et al., 2009; Meltzer, 2014; Riccio & Gomes, 2013; Swanson, 2001; Tamm et al., 2012). The provision of metacognitive support has been found to be important in teaching new learning skills to children with ASD (Bebko & Ricciuti, 2000; Bebko et al., 2021). Lastly, parent programs were excluded unless the program included a parent-mediated treatment, where parents specifically taught children inhibition or emotion regulation skills.

Secondary Screening

A secondary screening was performed after the final selection of the full text articles. Reference lists from eligible studies and relevant systematic reviews identified during the

literature search were manually searched to ensure that a comprehensive list of relevant articles was included. A forward search was also performed, by verifying whether any articles that cited the included articles met inclusion criteria. This secondary screening and search resulted in no new articles being added.

Data Extraction

A data extraction sheet was developed based on other systematic reviews looking at intervention programs for children in a clinical population (e.g., Chavez-Arana et al., 2018; Trembath et al., 2019) and the data extraction template from the Cochrane Consumers and Communication Review Group. The data extraction sheet was then pilot tested by the two reviewers (M.F and T.V.) on two randomly selected articles from the current review, and then refined accordingly. Lastly, the data extraction sheet was revised with a group of colleagues in the clinical developmental field with expertise in working with children with ASD. During the refinement stage, one additional variable to be extracted was added (i.e., severity of participants' ASD diagnosis).

For each study the following information was extracted: general information (i.e., authors, year, country, study design), demographic information about the sample(s) (i.e., diagnosis and severity, age, gender, sample size), characteristics of the intervention or program (i.e., type of intervention, duration, setting, provider, format, methods), description of control group (if available), outcomes measures and tools (e.g., measures of inhibition and emotion regulation, and of broader related concepts such as other executive functions or self-regulation), a brief summary of the study findings, and study follow-up (if available). All the extracted data were organized in an excel spreadsheet to facilitate data syntheses. One reviewer (M.F.) extracted the data from all included articles, while the second reviewer (V.T.) performed data

extraction for about a third of them. Of the eight articles from which data were extracted independently by both reviewers, the agreement rate was 100% on all items. Thus, it was assumed that the rest of the data extraction would be performed similarly.

Quality Assessments

The level of evidence and quality of each article were assessed independently by the two reviewers, and disagreement in ratings were resolved through discussion until a 100% agreement was reached. The quality rating of each study was measured using the Reichow's Method for Evaluating and Determining Evidence-Based Practice in Autism (Reichow et al., 2008). This evaluative method provides rubrics to evaluate the strengths and quality of both group and single subject design studies. This quality assessment tool was specifically designed and developed for research looking at interventions for ASD (Reichow et al., 2008) and is commonly used in systematic reviews for this population (e.g., Chang & Locke, 2016; Ferguson et al., 2019; Waddington et al., 2016). Using the rubric and the operational definition for each of the rating items (see Reichow et al. 2008), each article in the current review was assessed based on six primary quality indicators and six to eight secondary quality indicators, based on the research design (single-subject or group). Primary quality indicators are critical elements that are required for strong study validity and include items such as participant characteristics, and dependent and independent measures. Primary indicators were rated on a trichotomous scale as high (H), acceptable (A), or unacceptable (U) quality. Meanwhile, secondary quality indicators referred to important elements of research design that add important value to the research but are not necessary to establish validity. Secondary quality indicators included items such as interpersonal agreement, blind raters, procedural fidelity, social validity, and generalization and maintenance. For these items, a dichotomous scale was used, and items were rated as having evidence (E) or

no evidence (N). After evaluating each item on the quality scale, an overall descriptor of the strength of the study could be obtained (strong, adequate, or weak) depending on the number of primary and secondary quality indicators obtained (for more details view Reichow et al., 2008).

The Reichow evaluative method also provides an overall rating of evidence-based practice (EBP) based on the amalgamation of the final rating of each study. The scale includes information across both group-based and single-case based designs and provides criteria to determine whether a treatment may have established EBP or shows promising EBP (see Reichow et al., 2008 for details). This EBP rating scale provides a systematic way of evaluating the evidence supporting training programs and intervention for individuals with ASD, and has been reported to have good reliability and validity (e.g., Cicchetti, 2011; Reichow et al., 2008). Additionally, the criteria from the 2011 Oxford Center for Evidence-based Medicine (OCEBM) were used to further evaluate the level of evidence behind each study. Level of evidence ranged from 1 to 5, with Level 1 representing the highest level of evidence (systematic reviews) and Level 5 the lowest (mechanism-based reasoning). Given that systematic reviews were specifically excluded from the current review the highest level of evidence allowed on the OCEBM scale was Level 2 (randomized control trials).

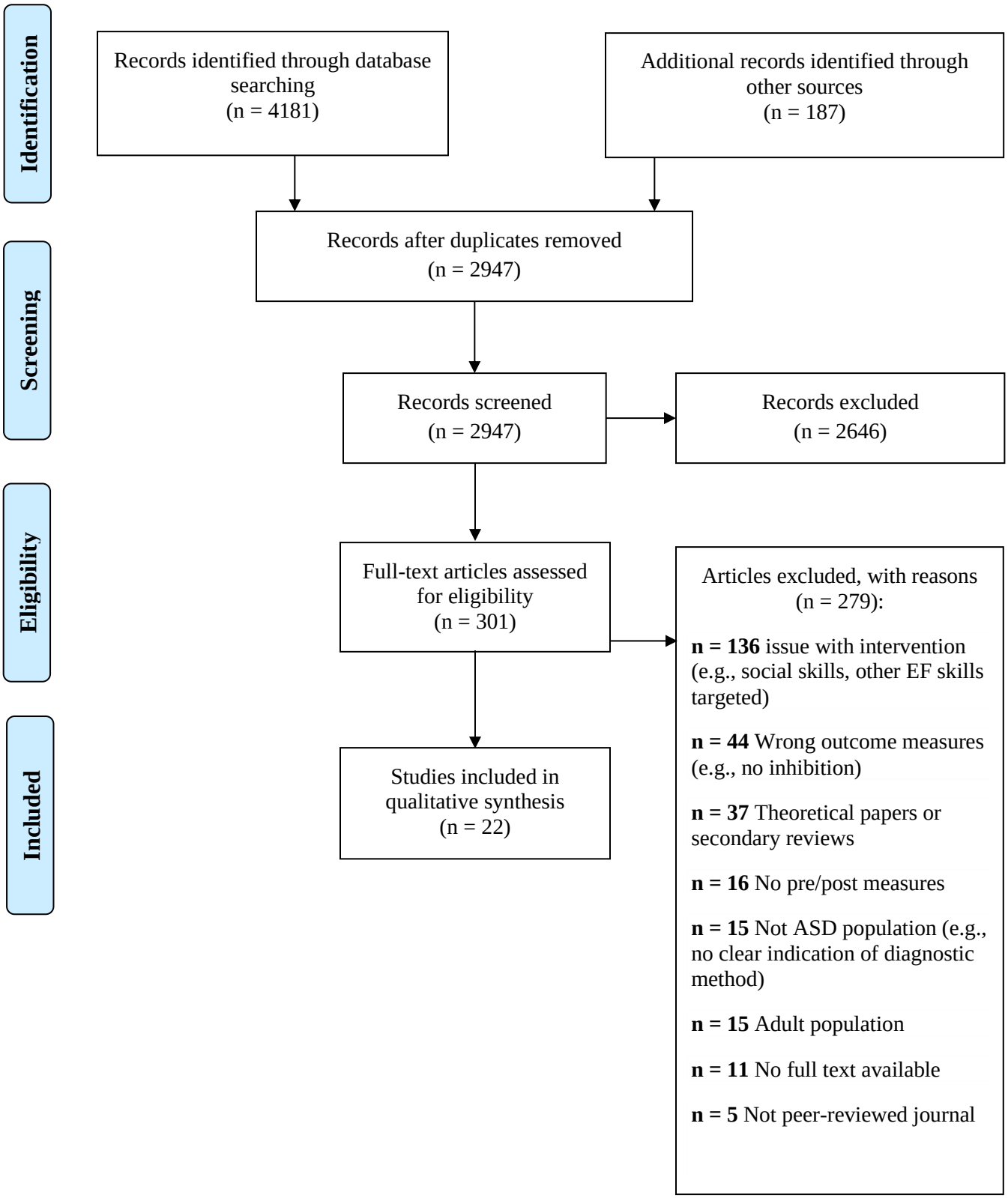
The effect of each intervention and whether results reported could be attributed to the intervention was also appraised by looking at the validity of included studies. Specifically, the risk of bias was assessed using the 13 items from the “Internal Validity-bias” and “Internal Validity-confounding (selection bias)” subsections of the Downs and Black (DB) Checklist for Measuring Study Quality (Downs & Black, 1998). Risk of bias was reported at the individual study level. Higher scores on the DB checklist indicate a lower risk of bias. Only a subsection of the DB Checklist was used as the Reichow’s scale already provided information on other areas

of quality assessment. The two raters evaluated each study independently using the Reichow evaluative method, the OCEBM, and the validity sections of the DB Checklist.

Data Synthesis

Due to the heterogeneity in data (i.e., wide age range, different ASD severity) and study design (single subject design, group design) a meta-analysis was not performed. However, information regarding the quality of each study and the level of evidence accumulated for a certain type of interventions (e.g., cognitive behavioural intervention) or a specific training program (e.g., Secret Agent Society: Beaumont, 2013) was reported. The extracted data were divided across two sets of tables, one containing information regarding intervention characteristics and main findings (Tables 6), and the other containing information relevant to quality assessment (e.g., design, generalization, maintenance of results, and quality ratings) (Tables 7). Additionally, all included studies were classified according to the main skills targeted in their intervention: inhibition or emotion regulation. However, a high degree of overlap was seen as several interventions appeared to target and measure outcomes in both. Therefore, interventions were primarily grouped based on types of intervention, while information on the impact of those interventions on both inhibition and emotion regulation skills were noted.

Figure 3. Prisma Flow Chart



Results

The literature search yield 4181 articles. After removing duplicates and screening the titles and abstracts, 301 articles remained and were assessed for full-text eligibility. In the end, 22 studies were included in the current systematic review. Figure 3 contains the full break down of why articles were excluded from the current review and how many articles remained after each screening step. The main reason for exclusion was issues with the intervention, which included absence of teaching component, the intervention included biomedical or physical procedures (e.g., transcranial stimulation), or inhibition and/or emotion regulation were not the main target of the intervention (e.g., interventions targeting social skills that indirectly influenced emotion regulation). Of the 22 included articles, seven interventions targeted inhibition (and other aspects of EF), ten targeted emotion regulation (and other components of self-regulation), and five targeted a combination of both skills.

Participants and Study Characteristics

A total of 553 children with ASD were included in the current systematic review, with sample sizes varying from 3 to 68 participants. Given the inclusion criteria, all participants in the study had a confirmed diagnosis of ASD. Across the 22 included studies, ASD diagnosis was confirmed using goal-standard diagnosis measures of ASD (e.g., Autism Diagnostic Observation Schedule; Autism Diagnostic Interview- Revised) or by reviewing psychological or psychiatric reports and ensuring that criteria for ASD diagnosis on the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) was met, and/or ASD symptom severity scales fell in the clinical range (e.g., Social Responsiveness Scales; Social Communication Questionnaire; Repetitive Behavior Scale-Revised). None of the included studies compared the effects of the intervention being assessed on children with ASD compared to other groups of children (e.g., children with

other neurodevelopmental disorders or TD peers). Therefore, sample sizes reported in Table 7 all represent ASD samples.

The average age across all studies was 9.6 years of age, ranging from 3 to 17 years. Most of the interventions were developed and administered for school age children (mean age between 6 and 12 years of age, n = 16), and only a small proportion of interventions were aimed at preschoolers (mean age of 5 years or less, n = 3) or adolescents (mean age of 13 years or more, n = 3). On average most samples were made up of male participants, ranging from 64% of the sample to 100%. Of the 21 studies in which the male to female ratio was reported, the average percentage of males in the sample was 82%. Few studies provided information on the severity of autism symptoms of participants (i.e., mild, moderate, or severe) and how it was determined (n = 4). Participants with intellectual functioning scores below 70 (i.e., in the impaired range) were often excluded, with 69% of studies that provided a measure of cognitive abilities specifying this exclusion criterion. Therefore, most interventions were targeted for participants without intellectual disabilities.

All studies were published between 2005 and 2021, with the majority between 2019 and 2021 (n = 13). Thirteen studies were conducted in North America, primarily the United States (n = 10), three in Europe, four in Asia, and two in Australia. All studies were written in English despite the attempt to include French articles.

Outcome Measures

A wide variety of measures (e.g., performance-and informant-based measures, observations) were used across the included studies to assess inhibition and emotion regulation skills, and related constructs. 55% of the studies (n =12) used both performance-based and

informant-based measures to assess the same skill of interest in participant (e.g., inhibition). The use of different types of measurement tools to assess a construct was more common for emotion regulation (n = 9) than for inhibition (n = 3). The Behavior Rating Inventory of Executive Functioning (BRIEF: Gioia et al., 2000a) was the most frequently used questionnaire to gather information on participants' EF skills, including inhibition, and overall behavioural regulation (which combines the inhibit, emotion control, and shift subscales). The most common children's performance measure for EF skills was the Wisconsin Card Sorting Task (WCST: Heaton et al., 1993), followed by the Trail Making Task (TMT: Reitan, 1958), the Color-Word Interference Tasks (CWIT: Delis et al., 2001), Walk/Don't Walk (W/DW: Manly et al., 1999), and other variations of these tasks (e.g., Heart and Flower Test: Davidson et al., 2006). For emotion regulation measures, half of the studies used direct observations, often using a behaviour tracking sheet filled out by participants' caregivers or teachers. The most common caregiver questionnaire used to measure emotion regulation in children was the Emotion Regulation Checklist (ERC: Shields & Cicchetti, 1997), followed by the Behavior Assessment System of Children (BASC: Reynolds & Kamphaus, 2004) which provided an index of change in emotion related challenges (e.g., anxiety). Meanwhile, few studies relied on children's perception of their own emotion regulation skills (n = 3). The most common one was the Children's Emotion Management Scale (CEM: Zeman et al., 2010). The use of vignettes to measure emotion regulation strategies that a child could come up with for a specific situation (e.g., "Dylan is being teased": Attwood, 2004) was the only performance-based measure of emotion regulation used. Five studies included measures of both inhibition/EF and emotion/self-regulation skills (Chan et al., 2013; Greco & De Ronzi, 2020; Phung & Goldberg, 2019; Ros-Demarize & Graziano, 2021; Tanksale et al., 2021).

Program Components and Outcomes by Types of Intervention

To facilitate comparison across different interventions targeting inhibition and/or emotion regulation skills in children with ASD, interventions were grouped based on their primary type of intervention (e.g., cognitive training, mindfulness-based). Grouping interventions this way makes identifying key components of these interventions more easily accessible. Across the 22 included studies, five primary types of intervention emerged: (a) cognitive training programs (n = 6), (b) cognitive behavioural therapy (CBT)/cognitive behavioural based interventions (n = 6), (c) mindfulness-based interventions (n = 5), (d) behavioural based interventions (n = 2), and (e) physical activity-based interventions (n = 3). Table 6 contains the extracted information from each study regarding intervention characteristics and main findings and these are organized based on primary intervention type.

Cognitive Training Interventions

Six of the included studies evaluated cognitive training interventions aimed at either improving inhibition skills (n = 5: Acero-Ferrero et al., 2017; Chen et al., 2020; Fisher & Happé, 2005; Macoun et al., 2020; Yerys et al., 2019) or emotion regulation skills (n = 1: Chu et al., 2020). All interventions targeting inhibition skills also targeted other executive functions, with working memory being the most common, followed by cognitive flexibility and attention. All cognitive training programs were designed for school age children (mean age of samples between 7.7 and 11.4 years old). Most of the cognitive training interventions were assessed on children with ASD without a comorbid intellectual disability, as only one study reported including some participants (n = 2) with IQ scores below 70 (Acero-Ferrero et al., 2017).

Of the studies that reported information on duration (5 out of 6), the duration of the interventions ranged from 4 days to 12 weeks, and with most lasting between two to three

months (n = 3). Individual sessions within an intervention varied from 25 to 50 minutes, with the majority being between 25 to 30 minutes in length (n = 4). The frequency at which the intervention took place ranged from once weekly to once daily. The cognitive training intervention targeting emotion regulation skills was delivered in a small group format (i.e., pairs) while all those targeting inhibition skills occurred in an individual format. None of the cognitive training interventions had a caregiver/parent component.

With the exception of the intervention developed by Fisher and Happé (2005), all other cognitive training interventions used computer-based games to improve the targeted skill of interest (Acero-Ferrero et al., 2017; Chen et al., 2020; Chu et al., 2020; Macoun et al., 2020; Yerys et al., 2019). No study used the same program (see Table 6), but engaging graphics and themed games were often used to increase engagement and participation. Common features across most cognitive training interventions targeting inhibition skills included the use of visual aids, immediate feedback, and repetition of skills as training methods, in addition to a scaffolded approach to learning (e.g., progressive increase in task difficulty based on child performance). All computerized cognitive training programs targeting inhibition skills were effective at improving inhibition skills from pre to post intervention as demonstrated by the report of significant results of intervention group over time on either informant- or performance-based measure of inhibition (see Table 6). The computerized cognitive training interventions targeting emotion regulation skills in children with ASD differed from the ones targeting inhibition. Specifically, techniques used in Chu and colleagues' (2020) intervention included the teaching of regulation strategies (i.e., deep breathing, muscle relaxation), cognitive change strategy (i.e., social stories, self-instruction, self-management), and attentional deployment strategy (i.e., focusing on a positive aspect of a situation). No exposure or explicit practice of these skills in a

different context were reported, and no training on emotion recognition was provided in this particular intervention (Chu et al., 2020). Chu and colleagues (2020) reported a significant decrease in the percentage of emotional behaviour problems based on observations following the intervention. Meanwhile, Fisher and Happé (2005) used an in-person approach to train inhibition skills in children with ASD using psychoeducation and hands on activities, and showed no improvement in targeted skills following the intervention.

Cognitive Behavioural Based Interventions

Six of the 22 included studies focused on assessing cognitive behavioural interventions targeting emotion regulation skills (Nowell et al., 2019; Scarpa & Reyes, 2011; Sofronoff et al., 2007; Swain et al., 2019; Thomson et al., 2015; Weiss et al., 2018). None of these CBT interventions were reported to target inhibition, or other executive functions, and none had outcome measures that could provide information on the effect of these interventions on inhibition skills. Half of the CBT interventions were designed for school age children between 8 to 13 years of age, while the other half were designed for younger children between the ages of 4 to 8 (see Table 6 for exact distribution). None the CBT interventions were assessed on children on the lower intellectual end of the spectrum (i.e., those with higher needs) as all studies either specifically excluded participants with IQs below 70 or specifically recruited participants with either Asperger or who would be considered “High-Functioning”.

The duration of the CBT interventions ranged from 6 to 12 weeks, with most lasting between 2 and 2.5 months in duration (n = 4). Individual sessions within an intervention varied from 60 to 120 minutes, with the majority being 60 minutes in length (n = 4). All CBT interventions occurred at a frequency of once a week. Four interventions were delivered in a small group format (i.e., group sizes between 2 and 4) and two were delivered on an individual

basis. All CBT interventions included a caregiver/parent component, often in the form of co-occurring parent sessions.

Five of the six CBT interventions targeting emotion regulation used very similar programs, as four of them were an adaptation of, or derived from, the work of Sofronoff and colleagues (2007). Two studies (Thomson et al., 2015; Weiss et al., 2018) specifically assessed the Secret Agent Society: Operation Regulation (SAS: OR, Beaumont, 2013), while the other two studies (Scarpa & Reyes, 2011; Swain et al., 2019) adapted Sofronoff and colleagues' (2007) intervention to be better suited for younger children. These interventions are all manualized, which is important when assessing treatment fidelity and for the wide dissemination of these interventions. Common features across these interventions included parent involvement, hands-on practice through social stories, short games, or planned systematic exposures, teaching of emotion regulation techniques (e.g., labeling and identifying emotions in oneself and others, and then learning emotion regulation skills), teaching of coping strategies (e.g., relaxation, deep breathing), weekly homework, and use of a token reinforcement system. Most interventions were also designed to follow either a spy or scientific/explorer theme to increase engagement and motivation. According to each study, all five of these CBT interventions significantly improved ER skills in children with ASD as assessed by caregivers. Additionally, improvements in ER skills were also noted on children's performance measures or behavioural observation measures, in four of these five studies (Scarpa & Reyes, 2011; Sofronoff et al., 2007; Swain et al., 2019; Thomson et al., 2015).

The last CBT intervention used a blended approach of cognitive and behavioural therapy (positive behavioural techniques) to help children improve their emotion regulation (and self-regulation skills more globally), through a parent-assisted intervention targeting both self-

regulation (concepts from the Zone of Regulation: Kuypers, 2011, which has a strong emphasis on recognizing emotions and emotion regulation) and social communication (Social Explorer Curriculum: Hendrix et al., 2013, 2016) (Nowell et al., 2019). Using measures created and developed specifically to assess their own intervention, Nowell and colleagues (2019) found improvement in participants' knowledge of emotion regulation and self-regulation strategies based on caregiver report, but not on children measures.

Mindfulness-Based Interventions

Five studies assessed mindfulness-based interventions targeting either emotion regulation skills (n = 2: Conner et al., 2019; Singh et al., 2011), inhibition and other EF skills (n = 1: Juliano et al., 2020), or a combination of both (n = 2: Chan et al., 2013; Tanksale et al., 2021). Most mindfulness-based interventions were designed for older children and adolescents with the mean age of participants ranging from about 12 to 16 years of age across four of the five studies (see Table 6). The remaining intervention (Tanksale et al., 2021) was designed for school-aged children (M = 9.4 years old). Only one of the included studies assessing mindfulness-based interventions reported including participants with lower intellectual abilities (IQ < 70) and this made up 30% of their sample (Chan et al., 2013).

The duration of most (4 out of 5) mindfulness-based interventions ranged from 4 to 16 weeks at a frequency of once or twice per week, with individual sessions lasting between 30 to 60 minutes. The remaining intervention required participants to perform a 30-minute mindfulness-based exercise (Meditation on the Sole of My Feet) twice daily until the extinction of the target behaviour (Singh et al., 2011). Three of the five interventions were delivered in a group format ranging from 2 to 20, with one of these interventions being also delivered on an individual basis for certain participants (Tanksale et al., 2021). Tanksale and colleagues (2021)

did not specifically assess differences between the delivery formats of their intervention. Two out of five mindfulness-based interventions included a caregiver component (Singh et al., 2011; Tanksale et al., 2021), one of which used parent-mediated approached to teach participants emotion regulation techniques (Singh et al., 2011).

The five mindfulness-based interventions varied significantly from each other, as some interventions appeared to pull from different methods and theories. No two studies assessed the same mindfulness intervention (see Table 6). Common features across mindfulness-based interventions targeting emotion regulation and/or inhibition skills in children with ASD included the teaching of relaxation techniques (i.e., grounding and breathing exercise), bringing body and emotion awareness, noticing wandering thoughts, and reconnecting with the present moment. Different techniques (e.g., meditation, yoga, Tai Chi like movements and breathing) were used across interventions to assist children with ASD become more mindful of bodily sensations and the link between body, mind, and emotions. All mindfulness interventions that specifically aimed at improving emotion regulation skills in children with ASD showed significant improvement on at least one measure of ER (informant-based questionnaires, behavioural observations, or child performance tasks). Similarly, all mindfulness-based interventions that targeted inhibition were also shown to improve inhibition skills based on either a child performance task (Chan et al., 2013; Juliano et al., 2020) or on caregiver reports (Tanksale et al., 2021). Although Juliano and colleagues' Mindful Schools program (2020) targeted both inhibition and emotion regulation skills, no measure of emotion regulation was used to assess the impact of this intervention on emotion regulation skills.

Behavioural Based Interventions

Two of the included studies evaluated interventions primarily founded in behavioural theories, with one specifically targeting emotion regulation (Rispoli et al., 2019), and the other targeting both inhibition and emotion regulation along with the broad constructs of EF and SR, respectively (Ros-Demarize & Graziano, 2021). Both behavioural-based interventions were designed for preschoolers (ranging between 3 and 6 years old), with no significant cognitive delays (IQ > 70) or significant language delays, and included a parent component. One study consisted of an intensive intervention, which occurred daily for two months, and the interventions was integrated within a summer program for pre-schoolers which ran for nine hours a day, five days a week (Ros-Demarize & Graziano, 2021). Meanwhile, the other intervention occurred at a frequency of once a week, with sessions lasting between 60 to 120 minutes, over the course of eight weeks (Rispoli et al., 2019).

Both behavioural-based interventions relied heavily on behavioural modification techniques and high levels of repetition to teach emotion regulation and/or inhibition skills. One intervention (RELACS) used a parent-mediated approach to teach emotion regulation skills to preschoolers with ASD (Rispoli et al., 2019). In this intervention, parents were taught how to identify children's emotions, model and use effective emotion regulation skills, and teach specific strategies to support emotion regulation in their child during naturalistic interactions or planned play time. The intervention was shown to improve emotion regulation skills (as rated by their caregiver) in 3 out of the 5 participants (Rispoli et al., 2019). Meanwhile, the other study evaluated a high intensity Summer Treatment Program for Preschoolers (STP-PreK) that used positive reinforcement strategies (e.g., visual reward systems, praises), psychoeducation, and interactive games, vignettes, and role-play to teach inhibition and emotion regulation skills (Ros-

Demarize & Graziano, 2021). Results of this study showed that following the STP-PreK intervention preschoolers with ASD showed improvement in both emotion regulation and inhibition skills on both informant-based questionnaires and child performance tasks.

Physical Activity Based Interventions

Lastly, three interventions used physical activities either in the context of martial arts (Greco & De Ronzi, 2020; Phung & Goldberg, 2019) or table tennis (Pan et al., 2017) to train inhibition skills in children with ASD. Both martial arts-based interventions also targeted emotion regulation skills (Greco & De Ronzi, 2020; Phung & Goldberg, 2019). All physical activity-based interventions were designed for school age children (M = 9 years old, see Table 6 for more details) and only one study included some participants with intellectual abilities below 70 (Phung & Goldberg, 2019). None of the interventions included a caregiver component. All physical activity-based interventions were delivered in a group format, occurred twice weekly for a duration of three months, with individual sessions lasting either 45 or 70 minutes.

The two interventions using martial arts had very similar curricula which taught inhibition (and other EF skills) within the context of learning complex sequences of movements, and by explicitly teaching the use and purpose of these skills when needing to stand still, attend to the instructor's demonstration, and when practicing movement sequences with other children and needing to control their force. Typically developing children were also part of the martial arts-based interventions and served as peer models for children with ASD (Greco & De Ronzi, 2020; Phung & Goldberg, 2019). Additionally, both martial arts interventions trained participants in learning breathing techniques and meditation as tools to regulate their body and mind. Participants also learned about the importance of regulating emotions and behaviours. Both martial arts-based interventions were shown to lead to significant improvements in inhibition and

overall EF skills, in addition to improvements in emotion regulation skills as measured by either performance-based measures and/or informant-based questionnaires. Meanwhile, in the table tennis program, inhibition skills were practiced through table tennis games (e.g., only hitting a ping pong ball back if it was a particular color, and not hitting balls of other colours). This program promoted improvements on a child performance task measuring inhibition and cognitive flexibility skills (Pan et al., 2017).

Table 6. Information on Interventions Assessed in Included Studies Organized by Type of Interventions

Authors (Year), Country	Age Range in Years (M)	Name of Int.	Target Outcome	Type of Int.	Delivery Mode (Group Size)	Duration	Caregiver Component	Measurement Tools	Main Findings- Treatment Group over Time
Cognitive Training Programs:									
Acero-Ferrero et al. (2017), Spain	5-12 (7.7)	PIFENA	Inhibit; WM; Planning; Regulation	Cog. Training, Computer-based	Individual	30min, 3x/week for 12 weeks	No	CHEXI (p)(t)	Inhibit (+) and WM (+)
Chen et al. (2020), Taiwan	6-12 (9.8)	CATS	Inhibit., Planning; Cog. Flex.	Cog. Training, Computer-based	Group (2)	50min, 1x/week for 8 weeks	No	WCST (c); TMT (c)	Inhibit (+) and Cog. Flex. (+)
Chu et al. (2020), Taiwan	8-14 (9.5)	e-Learning model	ER	Cog. Training, Computer-based	Individual	-	No	% negative emotional behaviours (o)	Negative emotional behaviour (+).
Fisher & Happé (2005), UK	6-15 (10.4)	EF Training	Inhibit; Cog. Flex.	Cog. Training, In-person	Individual	25min, 1x/day for 4-10 days	No	WCST (c); TMT (c)	Inhibit (0) and Cog. Flex. (0)
Macoun et al. (2020), Canada	6-12 (8.6)	Carribean Quest	Inhibit; Attention; WM	Cog. Training, Hybrid	Individual	30min, 3x/week for 8 weeks	No	KiTAP (c); WISC-IV - Spatial and Digit span (c); Colored Boxes task (c)	Inhibit (+), Selective Attention (+), Visual WM (+) Verbal WM (0), Sustained Attention (0), and Cog. Flex. (0).
Yerys et al. (2019), USA	9-13 (11.4)	Project EVO	Inhibit; WM; Attention	Cog. Training, Computer-based	Individual	25min, 5-7x/week for 4 weeks	No	BRIEF (p), TOVA(c), ADHD-RS-IV (p), CANTAB-WM (c)	Parent measures: EF(+), Attention & Impulsivity (+). Child tasks: attention (0) and WM (0).

Table 6. Cont.

Authors (Year), Country	Age Range in Years (M)	Name of Int.	Target Outcome	Type of Int.	Delivery Mode (Group Size)	Duration	Caregiver Component	Measurement Tools	Main Findings- Treatment Group over Time
CBT Programs:									
Nowell et al. (2019), USA	6-8 (6.8)	GoriLLA	SR: ER, CR, BR	CBT, Parent-assisted	Group (4)	90 min, 1x/week for 12 weeks	Yes	COP (c), PROGO (p)	Parent measures: child's SR skills (+). Child tasks: SR (0)
Scarpa & Reyes (2011), USA	4-7 (5.6)	No name	ER	CBT	Group (2-3)	60 min, 1x/week for 9 weeks	Yes	ERC (p); Behaviour Tracking (o); Vignettes-Emotion Reg. Strategies (c)	Parent measures: negativity/lability (+), ER skills (+), # outbursts (+). Child tasks: generating coping strategies (+).
Sofronoff et al. (2007), Australia	9-13 (10.8)	CBT for Anger Management	ER	CBT	Group (2)	120 min, 1x/week for 6 weeks	Yes	ChIA-P (p); Vignettes (c); Behaviour Tracking (o)	Parent measures: anger outbursts (+), ER skills (+). Child tasks: generating coping strategies (+).
Swain et al. (2019), USA	4-7 (6.2)	STAMP	ER	CBT	Group (2-4)	60 min, 1x/week for 9 weeks	Yes	ERC (p); Behavioural Tracking (o); Confidence in child's ER ability (p)	67% treatment responders. 50% negativity/lability (+). 66% # outbursts (+).
Thomson et al. (2015), Canada	8-12 (10.4)	SAS:OR	ER	CBT	Individual	60 min, 1x/week for 10 weeks	Yes	CEMS (c); Vignettes (c); ERC (p); BASC-2 (p)	Parent measures: ER skill (+), internalizing problems (+), and behavioural dysregulation (+). Child tasks: generating coping strategies (+).
Weiss et al. (2018), Canada	8-12 (9.8)	SAS:OR	ER	CBT	Individual	60 min, 1x/week for 10 weeks	Yes	CEMS (c); Vignettes (c); ERC (p); ERSSQ (p); BASC-2 (p)	Parent measures: ER skill (+), internalizing problems (+), and adaptive skill (+). Child tasks: ER skill (0).

Table 6. Cont.

Authors (Year), Country	Age Range in Years (M)	Name of Int.	Target Outcome	Type of Int.	Delivery Mode (Group Size)	Duration	Caregiver Component	Measurement Tools	Main Findings- Treatment Group over Time
Mindfulness Based Programs:									
Chan et al. (2013), China	6-17 (11.9)	Nei Yang Gong	SR: ER, CR, BR; and EF (inhib.)	Mind-body Program	Group (20)	60 min, 2x/week for 4 weeks	No	TOL (c), CCTT (c), FPT (c), Go/No Go task (c), ATEC (p)	Parent measures: child's outburst(+), behav.(+) and cog. awareness(+). Child tasks: SR(+), inhibit(+)
Conner et al. (2019), USA	12-17 (14.9)	EASE	ER	Mindfulness Based + CBT	Individual	45-40 min, 1x/week for 16 weeks	No	EDI (p); ABC-I (p); RSQ (p)(c); PROMIS (c)(p)	Parent measure: ER (+). 71% treatment-responders.
Juliano et al. (2020), USA	11-16 (13.6)	Mindful Schools	Inhibit, Cog. Flex, Attention	Mindfulness Based	Group (9-12)	30min, 2x/week for 8 weeks	No	CWIT (c); W/DW (c); CT (c)	Inhibit (+), Cog. Flex (+), and Selective Attention (+)
Singh et al. (2011), USA	14-17 (15.7)	Soles of the Feet	SR: ER, CR, BR	Mindfulness Based, Parent-Mediated	Individual	30 min, 2x/day-5 days; 2x/day until gone	Yes	Number of aggressive behaviours(o)	3 out 3 showed significant decrease in aggressive behaviours
Tanksale et al. (2021), Australia	8-12 (9.4)	Incredible Explorers Program	SR: ER; and EF	Mindfulness Based + CBT	Group (1-5)	60 min, 1x/week for 6 weeks	Yes	BRIEF (p), Anxiety Scale for Children(c)(p), EAQ (c)	Parent measures: child's EF (+), anxiety (0). Child tasks: sharing of emotions + willing to understand one's emotion (+), anxiety (0).
Behaviour Based Programs:									
Rispoli et al. (2019), USA	3-6 (4.5)	RELACS	ER	BT + Parent-mediated	Parent-child Dyad	60-120min, 1x/week for 8 weeks	Yes	TABS (p)	3 out of 5 ER (+)
Ros-Demarize & Graziano (2021), USA	3-6 (4.8)	STP-PreK	SR: ER, BR; and EF (inhibit, WM, Cog. Flex)	Behavioural Based Program	Group (9-11)	9 hrs daily for 8 weeks	Yes	HTKS(c), BRIEF(p), BASC-2(p), CST(c), Emotion Knowledge Task(c), AWMA(c), ERC(p)	Parent measures: child's ER (+), EF (+), ext. problems (+). Child tasks: Cog. Flex. (+), inhibit (+), WM (+), emotion knowledge (+).

Table 6. Cont.

Authors (Year), Country	Age Range in Years (M)	Name of Int.	Target Outcome	Type of Int.	Delivery Mode (Group Size)	Duration	Caregiver Component	Measurement Tools	Main Findings- Treatment Group over Time
Physical Activity Based Programs:									
Greco & De Ronzi (2020), Italy	8-11 (9.3)	Kata Karate Training	Inhibit; Cog. Flex.; Planning; Monitoring; SR: ER, BR	Physical Activity Based (Karate)	Group (5)	45min, 2x/week, for 12 weeks	No	BRIEF (p)	Overall EF (+) and ER (+)
Pan et al. (2017), Taiwan	6-12 (9.1)	Tennis Table	Inhibit; Cog. Flex.; Attention	Physical Activity Based (Table Tennis)	Group (1-2)	70min, 2x/week for 12 weeks	No	WCST (c)	Inhibit (+), Cog. Flex. (+)
Phung & Goldberg (2019), USA	8-11 (9.3)	Mixed Martial Arts	Inhibit; WM; Cog. Flex.; SR: ER, BR	Physical Activity Based (Mixed Martial Arts)	Group (12)	45min, 2x/week for 13 weeks	No	BRIEF (p); Hearts & Flowers Test (c)	Parent measure: EF (+), ER (+). Child tasks: Cog. Flex (+), Inhibit (+).

Note. BR = Behavioural Regulation, Cog. Flex. = Cognitive Flexibility, CT = Cognitive regulation, EF = Executive Functioning, ER = Emotion Regulation, SR = Self-regulation, WM = Working Memory, Inhibit. = Inhibition, Int. = Intervention, CBT = Cognitive Behaviour Therapy, CT = Cognitive Therapy, BT = Behavioural Therapy(-) = Unable to determine or not reported, (o) = Observations, (p) = Parent Measure, (c) = Children Performance Task, (+) = Significant improvement with $p<0.05$, (0) = No significant improvement. Abbreviations and full names of programs and measures: **CATS** = Comprehensive Attention Training System, **EASE** = The Emotional Awareness and Skills Enhancement program, **GoriLLA** = Growing, Learning, and Living With Autism, **PIFENA** = Executive Functions Intervention Programme for Children with Autism, **RELACS** = Regulation of Emotional Lability in Autism Spectrum Disorder through Caregiver Supports, **STAMP** = The Stress and Anger Management Program, **SAS:OR** = Secret Agent Society: Operation Regulation, **STP-PreK** = Summer Treatment Program for Pre-Kindergarteners, **ABC-I** = Aberrant Behaviour Checklist - Irritability subscale, **ADHD-RS-IV** = Attention-Deficit/Hyperactivity Disorder Rating Scale - Fourth Edition, **ATEC** = Autism Treatment Evaluation Checklist; **AWMA** = Automated Working Memory Assessment, **BASC-2** = Behaviour Assessment System for Children - Second Edition, **BRIEF** = Behaviour Rating Inventory of Executive Functions, **CANTAB-WM** = Cambridge Neuropsychological Test Automated Battery - Working Memory, **CCTT** = Children's Colour Trails Test, **CHEXI** = Childhood Executive Functioning Inventory; **ChIA-P** = Children's Inventory of Anger - Parent form, **CEMS** = Child Emotion Management Scales, **COP** = Child Observation Protocol, **CST** = Challenging Situations Task, **CT** = Cancellation Task, **CWIT** = Colour-Word Interference Task, **DKEF** = Delis-Kaplan Executive Function System, **EAQ** = Emotion Awareness Questionnaire, **EDI** = Emotion Dysregulation Subscale, **ERC-ER/LN** = Emotion Regulation Checklist - Emotion Regulation and Negativity/Lability subscale, **ERSSQ** = Emotion Regulation and Social Skills Questionnaire, **FPT** = Five Point Test, **HTKS** = Heads-Toes-Knees-Shoulders Task, **KiTAP** = Test of Attentional Performance for Children, **PROGO** = Parent Report of Group Outcomes, **PROMIS** = Patient-Reported Outcomes Measurement Information Systems, **RSQ** = Response to Stress Questionnaire, **SSIS** = Social Skills Improvement System Rating Scales, **TABS** = Temperament and Atypical Behaviour Scale, **TOVA** = Test of Variables of Attention, **TMT** = Trail-Making Test, **WCST** = Wisconsin Card Sorting Task, **W/DW** = Walk/Don't Walk, **WISC-IV** = Wechsler Intelligence Scale for Children - Fourth Edition

Level of Evidence and Quality of Studies

Most of the included studies were group design studies. Only two studies used a single case design (Rispoli et al., 2019; Singh et al., 2011). Of the group design studies, 13 were randomized control trial (RCT) studies (65%). Most of the RCTs used a waitlist control (n = 9) and some used an active control group (n = 4: Chan et al., 2013; Chen et al., 2020; Fisher & Happé, 2005; Yerys et al., 2019). The remaining seven intervention studies were either pilot, open-trial, or quasi-experimental design studies. Ratings on the O-CEBM for the studies ranged from Level 2 to Level 4, with Level 2 ratings indicating higher levels of evidence (view Table 7). The majority of RCT studies were rated as Level 2 except for three studies which were rated as Level 3 due to small sample size, or weak study design.

The overall rating for quality assessment using Reichow and colleagues' scale (2008) are presented in Table 7, while individual ratings for each item on the quality assessment scale are provided in the Supplemental Tables 4 and 5 in Appendix B. The most common methodological limitations for the primary quality indicators of single case studies were limited information regarding how the dependent variables were measured or coded, and insufficient information regarding the intervention (e.g., impossible to replicate the intervention). Meanwhile, the most common methodological limitations for the primary quality indicators of group studies were the absence of a control group, small sample size impacting statistical tests, and limited information regarding the intervention which impacts replicability. Fidelity and the use of blind raters were often missing from the group studies, in addition to interobserver agreement, and generalization or maintenance of results.

All included studies, except one (Fisher & Happé, 2005), reported significant improvements from pre to post intervention on at least some of their outcome measures of

inhibition and/or emotion regulation skill. However, based on Reichow's quality rating scales most of the studies included in this systematic review received an overall quality rating of "weak" (n = 15) due to limitation in study design. Seven studies received a rating of "adequate", one of which was a single-case design study (view Table 7). None received a rating of "strong". Additionally, no individual intervention met criteria to fall in the "Established Evidence Based Practice (EBP)" level based on Reichow and colleagues' (2008) evidence-based ratings rubric. In an analysis that grouped interventions based on intervention types, three types of interventions targeting inhibition and/or emotion regulation in children with ASD showed promising evidence: (1) cognitive behavioural interventions for emotion regulation; (2) mindfulness-based interventions for inhibition and emotion regulation (or the broader concept of self-regulation); and (3) physical activity-based, specifically martial arts programs, for inhibition and emotion regulation (or the broader concept of self-regulation). Each of these intervention types had at least two separate group designed studies that obtained an adequate quality rating.

Risk of Bias

On average, the included studies obtained a score of 5.7 out of 12 on the risk of bias items (range: 1-12), indicating that the majority of studies did not include or report the use of design and measurement strategies that mitigate the risk of bias (view Table 7). The most common missing factors included a lack of random assignment, blinding of participants to the intervention they received, and blinding the interventionist or researcher assessing the main outcome of the intervention. Additionally, very few of the included studies reported having pre-registered their study and analysis plan, which is an important factor to limit data dredging (also called data fishing or data mining). Data dredging refers to performing a large number of analyses to find significant results. Supplemental Table 6 in Appendix B provides a breakdown

of the individual scores for each of the items from the DB checklist for each included study. Two studies received scores higher than 10 on the risk of bias checklist, indicating high levels of methodological quality (Chan et al., 2013; Weiss et al., 2018).

Generalization and Maintenance

Ten of the included studies in the current review had a follow-up period after the intervention to assess maintenance of gains (view Table 7). Three of these studies (Chen et al., 2020; Fisher & Happé, 2005; Rispoli et al., 2019) failed to show maintenance of skills at follow up, resulting in only seven studies demonstrating some maintenance in skills learned. The timing of the follow-up assessment varied from four weeks post-treatment to three years. Meanwhile, generalization of findings was harder to assess and evaluate. In the current review, generalization is viewed as the transferability of the trained skill to a new setting (e.g., school or home/everyday environment if targeted skills were trained within a clinical setting/outside the home). Of the 22 included studies, four showed generalizations of skills based on the above definition (Table 7).

Table 7. Quality Assessment of Studies and Relevant Information Divided by Intervention Type

Study	n (% male)	Study design	Control group	Follow-up	Attrition (%)	Maintenance (Y/N)	Generalization (Y/N)	Quality Score	DB- Risk of Bias	Level of evidence
Cognitive Training Programs:										
Acero-Ferrero et al. (2017)	7(-)	Pilot study	None	None	0%	-	Y	W	2	Level 4
Chen et al. (2020b)	25(92%)	RCT	Social skills training	24 weeks	-	N	-	W	5	Level 2
Chu et al. (2020)	8(88%)	Pilot study	None	None	-	-	-	W	1	Level 4
Fisher & Happé (2005)	27(-)	RCT	ToM group + no intervention group	6-12 weeks	-	N	-	W	5	Level 3
Macoun et al. (2020)	20(85%)	RCT	WLC	None	13%	-	-	W	8	Level 2
Yerys et al. (2019)	19(89%)	RCT	Educational intervention	None	5%	-	-	W	6	Level 3
Behaviour Based Programs:										
Rispoli et al. (2019)	5(80%)	Multiple single-case	None	12 weeks	0%	N	-	W	4	Level 4
Ros-Demarize & Graziano (2021)	37(87%)	Quasi experiment	None	24 weeks	0%	Y	Y	W	8	Level 3
Physical Activity Based Programs:										
Greco & DeRonzi (2020)	28(86%)	RCT	WLC	None	0%	-	-	A	7	Level 2
Pan et al. (2017)	22(100%)	RCT	WLC	12 weeks	-	Y	-	W	8	Level 2
Phung & Goldberg (2019)	34(82%)	RCT	WLC	None	0%	-	Y	A	6	Level 2

Table 7. Cont.

Study	n (% male)	Study design	Control group	Follow-up	Attrition (%)	Maintenance (Y/N)	Generalization (Y/N)	Quality Score	DB- Risk of Bias	Level of evidence
CBT Programs:										
Nowell et al. (2019)	17(77%)	RCT	WLC	12-24 weeks	6%	Y	-	W	6	Level 2
Scarpa & Reyes (2011)	11(82%)	RCT	WLC	None	8.30%	-	-	W	3	Level 3
Sofronoff et al. (2007)	45(96%)	RCT	WLC	6 weeks	0%	Y	Y	A	6	Level 2
Swain et al. (2019)	18(89%)	Open trial	None	None	0%	-	-	W	3	Level 4
Thomson et al. (2015)	14(93%)	Open trial	None	None	7.10%	-	-	W	7	Level 3
Weiss et al. (2018)	68(88%)	RCT	WLC	10 weeks	11.80%	Y	-	A	12	Level 2
Mindfulness Based Programs:										
Chan et al. (2013)	40(90%)	RCT	Progressive Muscle Relaxation	None	13%	-	-	A	10	Level 2
Conner et al. (2019)	17(88%)	Open trial	None	None	15%	-	-	W	4	Level 3
Juliano et al. (2020)	27(78%)	Open trial	None	None	7%	-	-	W	4	Level 3
Singh et al. (2011)	3(100%)	Multiple single-case	None	3 years	0%	Y	-	A	3	Level 4
Tanksale et al. (2021)	61(64%)	RCT	WLC	6 weeks	9%	Y	-	A	8	Level 2

Notes. RCT = Randomized control trial, WLC = Waitlist control, (-) = Unable to determine or not reported. DB = Downs and Black Checklist for risk of bias. W = Weak; A = Adequate. Quality Score is based on Reichow et al., (2008) scale. Level of evidence is based on O-CEBM criteria. All sample sizes refer to ASD samples as no study used comparison groups with other populations.

Discussion

The current systematic review provides a summary of the characteristics and effects of interventions aimed at improving inhibition and/or emotion regulation in children with ASD. This is the first systematic review that simultaneously looks at studies evaluating interventions for children with ASD that target inhibition and emotion regulation skills together. Previous systematic reviews have either reviewed one of these areas (e.g., Granville, 2020) or have reviewed only one type of intervention at a time, such as the effect of cognitive training interventions on EF more broadly (Bourgeois et al., 2019; Pasqualotto et al., 2021). The present systematic review, which included different types of interventions targeting both inhibition and emotion regulation, provided the opportunity to observe the conceptualization of inhibition and emotion regulation constructs in the design of interventions for children with ASD. Given that inhibition skills have been postulated to play an important role in the development of emotion regulation skills in children with ASD (e.g., Jahromi et al., 2013; Mazefsky & White, 2014) and often occur simultaneously in the real world, examining how both constructs can be targeted individually or concurrently will provide guidance for both professionals and caregivers working with these children. In addition, this perspective of both inhibition and emotion regulation provides the opportunity to observe common intervention characteristics within and across these targeted outcomes and how to best support their development. Of the 22 included studies, 7 assessed interventions targeting inhibition (and other aspects of EF), 10 evaluated interventions targeting emotion regulation skills (or self-regulation more broadly), and 5 assessed interventions that were designed to support the development of both inhibition and emotion regulation skills, and the broader construct in which these skills operate.

Level of Evidence and Quality of Studies

All but one of the included studies indicated significant improvement in at least some aspect of inhibition and/or emotion regulation in children with ASD following the interventions. Of those, seven studies showed maintenance of gains at follow-up. Although these results demonstrate promising treatment avenues for children with ASD, it is important to consider the publication bias that exists in the literature, where studies with non-significant results are less likely to be published (e.g., Levine et al., 2009; Sutton et al., 2000; Thornton & Lee, 2000). Therefore, evidence behind these interventions must be appraised for more than just significant increases in outcome measures, but also by the quality of the study design and analyses, and the replication of those results across multiple studies.

Most of the included studies received a quality rating of weak due to study design and lack of methodological rigour to limit the risk of biases. Overall, only two studies showed limited risk of biases: these were the interventions reported by Weiss and colleagues (2018), who assessed a cognitive-behavioural intervention targeting emotion regulation skills in children with ASD, and Chan and colleagues (2013), who evaluated a mind-body intervention targeting both emotion regulation and inhibition skills. Therefore, the results presented in the current systematic review need to be interpreted with caution as more thorough research with methodologies that mitigate the risk of bias is required for these interventions for children with ASD to reach the evidence-based status.

Although most studies received a quality rating of weak due to study designs, these ratings need to be understood within the context of an emerging field of research. Research looking specifically at assessing inhibition and emotion regulation interventions in children with ASD is relatively new. This emergent stage is reflected in the current systematic review as the

majority of included studies were published in the last five years. Previous research has mostly focused on identifying challenges in EF and emotion regulation in children with ASD (e.g., Kenworthy et al., 2009; Pellicano, 2012; Willcutt et al., 2008), and fewer studies have focused on assessing interventions targeting these areas of needs. The logical steps of building evidence for a treatment are first to run pilot studies and then move toward randomized control trial (RCT). Specifically, large RCT with thoughtfully selected active control groups can provide critical information regarding what key components of an intervention is contributing to positive outcomes (Rossi et al., 2018). Given this intervention research progression, it was expected that several studies included in the current systematic review would be pilot studies with small sample sizes and that most RCT studies would be design with waitlist controls. The next step for intervention research in this field would be to include more RCT studies with active control groups. Using active control groups in future research is recommended so that, there is a comparison group in which participants are actively involved in some attention control task (e.g., colouring group, another intervention program, story telling, etc.) during the intervention period. Future research comparing existing intervention programs for children with ASD with an active control group is needed to gain a better understanding of which aspects of the interventions are linked with improvements in emotion regulation and inhibition skills.

Intervention Characteristics by Outcome Targets

The studies that met the inclusion criteria differed greatly from each other in terms of study design, statistical analyses, sample sizes, degree of information provided on measures and interventions, and in terms of intervention type and format. Five broad categories of intervention types emerged: (a) cognitive behavioural based intervention, (b) mindfulness-based interventions, (c) physical activity-based interventions, (d) cognitive training programs, and (e)

behavioural based interventions. Although no individual intervention met criteria for established evidence-based practice, three types of interventions targeting inhibition and/or emotion regulation in children with ASD showed promising evidence: (1) cognitive behavioural interventions targeting emotion regulation skills in school age children; (2) mindfulness-based interventions targeting both inhibition and emotion regulation skills in school age children; and (3) group physical activity-based interventions, specifically martial arts programs, targeting inhibition and emotion regulation in school age children delivered in the community with typically developing peers acting as role models.

Cognitive Behavioural Interventions

The results from the current systematic review indicate that research assessing interventions targeting emotion regulation skills in children with ASD is primarily grounded in cognitive behavioural therapy. CBT-based interventions have commonly been implemented with children and adults with ASD (for review see Rotheram-Fuller & MacMullen, 2011; Spain et al., 2015). These interventions have been shown to be effective at reducing various symptoms such as anxiety (e.g., Lang et al., 2010; Wood et al., 2009). Therefore, it is not surprising that most interventions targeting the regulation of emotions would be grounded in CBT as well.

Across the six included studies that assessed CBT interventions, all demonstrated gains in emotion regulation skills following the interventions. However, there was limited information regarding the long-term effects and maintenance of these gains post intervention. These interventions typically involved teaching children to label and recognize emotions in themselves and others, while also teaching adaptive coping strategies and when to use these strategies. These components were often imbedded in either a spy or explorer theme-based curriculum that followed a highly structured manualized intervention. Different delivery formats were used

across interventions, with some designed to be administered on an individual basis (e.g., Weiss et al., 2018), while others were delivered in a small group format (e.g., Sofronoff et al., 2007). With regards to children with ASD specifically, an argument could be made for both individualized and group format interventions. Individualized treatments provide the opportunity to tailor interventions to the specific need of the individual. Given the heterogeneity in ASD presentation (e.g., Masi et al., 2017) and in core EF and emotion control skills in this neurodiverse group (see Chapter 2), it is possible that an individual approach may be most effective. Meanwhile, interventions delivered in groups may indirectly help promote and facilitate the development of social skills, which would be beneficial for those children with ASD who struggle greatly with social communication skills (APA, 2013). Although beyond the scope of the current study, several cognitive behavioural based interventions incorporate emotion regulation training as a component of social skills training (e.g., Beaumont & Sofronoff, 2008; Beaumont et al., 2015, 2019; Sofronoff et al., 2017). Most of these interventions are delivered in a group format, illustrating some of the advantages that a group format may have for individuals with ASD. However, given that these interventions did not specifically focus on training emotion regulation skills, they were excluded from the current systematic review.

Another common factor across all CBT-based interventions targeting emotion regulation skills in children with ASD was the involvement of caregivers in the intervention, mostly through psycho-educational sessions informing caregivers about the skills being taught to their children. Involving caregivers in interventions for children with ASD has been argued to support the generalization of skills of learned (e.g., Burrell & Borrego, 2012), and to support the development of co-regulation (e.g., Cibralic et al., 2019; Gulsrud et al., 2010). Including caregivers in interventions, especially in early childhood intervention, has been shown to

increase social communication abilities in the child with ASD (Aldred et al., 2004), decrease parental depression and stress (e.g., Koegel et al., 1996), help increase parents' knowledge about ASD (e.g., Jocelyn et al., 1998), and serve as a strong predictor of treatment outcomes (e.g., McConachie & Diggle, 2007). Although the cognitive-behavioural interventions included in the current review may have supported the generalization of learned skills across different contexts as a result of the high degree of involvement of caregivers, there was limited assessment of generalization of skills in these intervention studies.

Mindfulness-Based Interventions

The results from the current systematic review indicate promising evidence for mindfulness-based interventions targeting both emotion regulation and inhibition skills in children with ASD. It is important to note that most of the mindfulness-based interventions in the current review might be categorized as "third-wave CBT" interventions. Third-wave CBT intervention are those that integrate components of mind-body practice, especially mindfulness, and cognitive behavioural therapy, such as teaching strategies to recognize emotions and learning tools to cope with these emotions (e.g., Hayes & Hofmann, 2017). Therefore, there is considerable overlap between these interventions and the cognitive behavioural programs discussed in the previous section.

Different methods were used in these interventions to assist children with ASD to become more mindful of bodily sensation and the link between body, mind, and emotions. The methods included meditation (Singh et al., 2011), yoga (Tanksale et al., 2021), and Nei Yang Gong (i.e., the use of slow, calm and purposeful movement like in Tai Chi: Chan et al., 2013). Common features included the teaching of relaxation techniques (i.e., grounding and breathing exercises), bringing body and emotion awareness, noticing wandering thoughts, reconnecting

with the present moment, and often the use of CBT techniques to support the regulation of emotions, behaviour, and thoughts. Across the five included studies that assessed mindfulness-based interventions, all demonstrated gains in either inhibition and a broader range of executive functions (Juliano et al., 2020) or in emotion regulation (Conner et al., 2019; Singh et al., 2011) or in both (Chan et al., 2013; Tanksale et al., 2020). However, few of these intervention studies included an evaluation of the long-term effects and maintenance of these gains post intervention.

Despite the promising results, the broad range of mindfulness-based interventions included in the current review made it challenging to identify which components of this type of intervention are particularly helpful in improving inhibition and emotion regulation skills. Is it the physical component (e.g., physical activity from Yoga or the Tai Chi like program), the practice of exerting top-down processes to remain in control of one's movement, thoughts, and bodily sensation, or a combination of both that is contributing to improvements in emotion regulation and inhibition? Mind-body practice has been hypothesized to promote self-regulation more globally by using both bottom-up and top-down processes (Haydicky et al., 2012; Rashedi & Schonert-Reichl, 2019; Schmalzl et al., 2016; Taylor et al., 2010). More specifically, attention regulation is a top-down process that is used in mindfulness and other mind-body practices to respond to internal and external stimuli in a voluntary manner instead of a reactive manner (e.g., Churchill et al., 2010; Jha et al., 2017). Top-down processes to regulate attention have been commonly linked to inhibition skills (e.g., Barkley, 1996; 1997). Additionally, top-down processes are used in mindfulness-based practice to let go of ruminating thoughts or difficult feelings (e.g., for more details see Harris, 2019), which are important components of emotion regulation. Meanwhile, experiential awareness and introspection of internal bodily sensation are common bottom-up components included in mind-body practices and can be helpful in

recognizing emotions in oneself (Guendelman et al., 2017), a critical first step in emotion regulation (e.g., Cole et al., 2004). Interventions teaching mindful skills are likely to have a positive impact on both inhibition and emotion regulation skills given how the different components of mindfulness are linked to these skills. In a systematic review looking at the effects of mindfulness- and yoga-based interventions in youth with ASD, Semple (2019) found some evidence that these intervention programs helped with self-control and emotion regulation. However, empirical evidence supporting this type of intervention was inconclusive (Semple, 2019), indicating that more research on the effects of mind-body practice in children with ASD is still needed.

Physical Activity-Based Interventions

The third type of intervention that showed promising evidence for targeting inhibition and emotion regulation skills in children with ASD, were physical activity programs based in martial arts. Common features of these interventions were the use of repetitive drills and activities embedded within a sport (i.e., martial arts) that were taught in a scaffolded manner, along with the teaching of mindfulness and mind-body awareness techniques (Greco & De Ronzi, 2020; Phung & Goldberg, 2019). These interventions were delivered within the community in a group format with typically developing children acting as peer support and participating in hand-on activities with children with ASD. Although no caregiver component was included in these interventions, including typically developing peers may help with the generalization of the learned skill as modeling is an important aspect of learning and developing new skills (e.g., observational learning- Bandura & Menlove, 1968). Martial arts have also been argued to be closely linked to mindful practice (e.g., Naves-Bittencourt et al., 2015) and thus

these interventions shared some overlapping components with the mindfulness-based programs mentioned above.

Exercise and physical activity in general have been shown to help reduce repetitive patterns of behaviour and to improve social communication skills and cognitive abilities in children with ASD (for review see Sorensen & Zarrett, 2014; Sowa & Meulenbroek, 2012). Given that both martial arts interventions reviewed here used a RCT design with a waitlist control instead of an active control group (Greco & De Ronzi, 2020; Phung & Goldberg, 2019), it is difficult to identify which aspect of the intervention is supporting the development of inhibition and emotion regulation skills. It is possible that improvements in these skills are simply a by-product of the physical activity program helping with other ASD symptoms. Therefore, future studies should focus on manualizing these physical activity-based interventions and conducting randomized control trials with an active control, such as a program that teaches progressive muscle relaxation in small groups, or where children are engaged in physical activities (e.g., jungle gym) for the same amount of time per week. These studies would provide further evidence for this treatment type for children with ASD and provide further information regarding what aspects of the intervention are truly supporting the development of inhibition and emotion regulation skills.

Cognitive Training and Behavioural Based Interventions

Lack of evidence supporting cognitive training and behavioural-based types of interventions targeting inhibition or emotion regulation skills was found. With regards to behavioural based interventions, no study evaluated the effects of these types of programs using a RCT design limiting conclusions that can be drawn regarding their efficacy. However, the results of the current systematic review do seem to indicate that behavioural based interventions

targeting emotion regulation and inhibition skills may be a good avenue for preschool age children with ASD (e.g., Ros-Demarize & Graziano, 2021), but more research is needed. The current review revealed limited support for cognitive training programs targeting inhibition skills more specifically, mostly due to lack of maintenance and generalizations of the skills being trained. These results are consistent with the current literature on cognitive training in children more generally (Diamond, 2012). In their review article, Diamond and Lee (2011) stated that across training programs aimed at developing EF skills in children, the gains seen in one executive function are rarely transferable to other EF skills, especially for computer-based EF training programs (e.g., Bergman Nutley et al., 2011; Thorell et al., 2009). If this is the case for typically developing children, it is expected that individuals with ASD, who generally present with difficulties in generalizing learned skills across different contexts (Bellini et al., 2007; Fein et al., 1979; Hume et al., 2009; Rimland, 1964; Matthews et al., 2001; White et al., 2007), would struggle even more. Therefore, children with ASD may need more direct support to make associations between the skills learned during computerized cognitive training and how those skills could apply to their everyday life. Future programs targeting inhibition skills specifically may want to consider a hybrid model that would include both a computerized aspect to practice some of the skills in a low-risk environment while also including hands-on practice in the child's environment with the support of an interventionist to improve generalization across contexts.

Limitations and Future Directions

There are a number of limitations to this review. First, the review process for selecting studies for the current systematic review were limited to only English and French articles. Secondly, participants across the included studies did not fully represent the broad diversity that is typically seen across the autism spectrum, especially in regard to age, cultural diversity, and

intellectual abilities. The majority of the intervention programs in the current review were designed for school age children (6-12 years old) from English-speaking countries with no severe delays in their intellectual abilities. This narrower representation of children on the spectrum is consistent with results from other systematic reviews of different interventions for children with ASD (e.g., Ratliff-Black & Therrien, 2021; Vasa et al. 2014). However, this narrow context is important to note, as the results of the interventions presented in the current review may not generalize to all children on the spectrum. For example, the majority of the studies reviewed here used samples that were predominantly male. Although this is consistent with the prevalence rate of ASD in children (4 to 1: male to female ratio) (APA, 2013; Loomes et al., 2017), it offers very limited information regarding how these interventions may support young girls with ASD. This is an important limitation to consider given that research has indicated some differences in EF and emotion regulation skills between girls and boys with ASD (view Lemon et al., 2011; White et al., 2017; Wieckowski et al., 2020). Similarly, despite the elevated co-occurrence rate of ASD and intellectual disability (see Chakrabarti & Fombonne, 2005; Fombonne, 2003), only three of the 22 studies included in this review reported having some participants with significant delays in cognitive abilities, making it impossible to determine how this subgroup of children responds to these interventions.

Clinical Recommendations and Conclusion

There is a growing recognition that interventions aimed at improving emotion regulation and inhibition skills in children with ASD are needed and could play an important role in the development and adaptive functioning of these children. The current systematic review revealed a spike in research examining the effects of interventions in these areas in the last five years. Although research in this area is still relatively new, there are promising results for different

types of interventions that may support the development of inhibition and/or emotion regulation skills in children with ASD. Cognitive behavioural interventions that include a caregiver component, mindfulness-based interventions, and group-based martial arts interventions have all shown emerging evidence at supporting the development of inhibition and/or emotion regulation skills in children with ASD. Clinicians looking to use these interventions in their work, must be aware that most interventions have only been tested on specific subgroups of children with ASD, and therefore, these interventions may not be well suited for children with ASD. More robust research is still needed to provide evidence of the effectiveness of these interventions for children with ASD across a broader age range and functioning level

Chapter 4: General Discussion

The overall purpose of this manuscript was to gain a deeper understanding of core executive functions and emotion regulation skills in children with ASD and how they have been targeted in interventions for this population. Two studies were conducted to accomplish this goal. The first study explored the heterogenous presentation of core EF and emotion control skills in ASD, while the second study gathered evidence on whether some of these skills have been effectively trained in children with ASD. In the following sections, I will first provide an overview of the main findings across both studies, while exploring their overlap and how these results informed each other. Then, results of both studies will be integrated to discuss the clinical implication of these findings and how they may be used to inform interventions for children with autism, along with discussing future research in this field.

Summary of Findings

Using a latent profile analysis, the first study identified three profiles based on core executive functions and emotion control skills in children and adolescents with ASD: *Broadly Affected, Narrowly Affected,* and *Intact*. The profiles varied based on these children's inhibition, emotion control, cognitive flexibility, and working memory abilities in everyday life as reported by their caregivers. One profile was marked by no clinically significant impairments in all four areas of interest, the second showed impairment in only some aspects of EF, specifically working memory and shifting, and the third showed more generalized challenges across all four skills. Understanding the heterogeneity of EF and regulation skills in children with ASD is an important first step for the development of effective treatments and interventions. The results from the first study indicate that core EF and emotion control skills in children with ASD varied greatly from individual to individual, and that not all children with ASD present with significant challenges in

these areas. Therefore, a “one-size fits all” treatment approach for all children with autism will likely not be very effective. The profiles identified in the first study provide an avenue for more targeted interventions for subgroups of children with ASD with similar patterns skills. For example, results showed that when significant challenges in emotion control and inhibition are present, children with ASD tend to have challenges across a broader range of EF and self-regulation skills. Children who presented with this type of profile also tended to have more severe ASD symptoms and greater challenges in other behavioural and emotional domains as compared to children in the other two profiles. As a result, targeting inhibition and emotion regulation skills in children with ASD who present with this specific profile may be especially beneficial.

Building on the findings from the first study, a systematic review looking at the evidence and components of pre-existing interventions targeting inhibition and emotion regulation skills for children with ASD was conducted. Results from this second study identified 22 studies that met inclusion criteria. Studies varied greatly on type of interventions, targeted outcomes, format of delivery, and overall study designs. Although almost all studies reported positive outcomes in some aspect of inhibition and/or emotion regulation skills post intervention, the empirical evidence supporting these interventions in children and teenagers with ASD was inconclusive. Evidence behind these interventions must be appraised for more than just significant increase in outcome measures, but also for the quality of the study design and analyses, and the replication of those results across multiple studies using the same intervention. Additionally, most interventions were assessed in predominantly male English-speaking samples made up of mostly school age children with no known intellectual disability, limiting the generalizability of results to all children with ASD.

Even though no single intervention met criteria for established evidence-based practice on the Reichow and colleagues' (2008) evaluative scale, various types of interventions were identified as showing promising results. These included cognitive behavioral based interventions for emotions regulation skills, mindfulness-based interventions for inhibition and emotion regulation skills, and group-based martial arts programs for inhibition and emotion regulation skills. Common features identified across most of these promising interventions included the recurrent and frequent practice of the skills being learned, a scaffolded approach to learning a new skill, the inclusion of caregivers or peers to support learning, and the explicit teaching of the connection between the mind and the body and real-world use. The results of the second study provide valuable information regarding what types of interventions targeting inhibition and emotion regulation for children with ASD already exist, the evidence behind them, and the tools and components of these interventions that seem most important in the training of these skills. This information can be valuable for clinicians in the field, and for individuals involved in developing or refining interventions in these targeted areas.

Common Themes and Clinical Implications

Although the two studies in the current manuscript had vastly different research goals, they overlap in their objective of informing the development and refinement of training programs aimed at supporting the broader development of EF and self-regulation skills in children with ASD. Across both studies, complementary themes regarding the relationship between core executive functions and components of self-regulation, especially emotion regulation, in children with ASD emerged.

Close Relationship between Inhibition and Emotion Regulation

Results from both studies highlighted the important role of inhibition and emotion regulation as avenues for intervention in children with ASD. In the first study, it was found that more than a third of children with ASD present with clinically significant challenges in inhibition and/or emotion control. Difficulties in these areas are not limited to younger children but occur across the ages of 6 to 17 years old. Additionally, clinically significant challenges in inhibition and emotion control were associated with profiles of children more likely to show challenges in other core EF skills, more severe ASD symptoms, and greater emotional and behavioural challenges. This finding was consistent with previous research demonstrating that inhibition and emotion regulation skills in children with ASD can be predictive of ASD symptoms and the presence of internalizing and externalizing challenges (e.g., Livesey et al., 2006; Mazesfky et al., 2014; Mostert-Kerckhoffs et al., 2015; White et al., 2013). Additionally, this finding supports the notion that EF and self-regulation skills are likely playing a role in the broad clinical presentation of ASD. Given the heterogeneity in EF and emotion control skills in children with ASD, these skills should be carefully evaluated during comprehensive assessments as they could inform future steps, including referral for targeted interventions.

Previous research on training programs targeting EF skills in typically developing children have demonstrated that children with lower levels of EF are the ones most likely to benefit from these targeted interventions (e.g., Diamond, 2012; Flook et al., 2010; Karbach & Kray, 2009). According to the profiles from the first study, children with ASD who present with significant challenges in inhibition and emotion control are the ones who are more likely to exhibit broadly affected EF skills. Thus, interventions specifically targeting inhibition and emotion regulation skills have the potential of having positive rippling effects on the

development of other core EFs, while also supporting the emergence of other critical skills that may help reduce ASD core symptoms.

As demonstrated by the results of the second study, there has been a rise in interest in the last few years for developing and evaluating programs that target inhibition and emotion regulation skills in children with ASD, adding evidence of the importance of training these skills. Almost all interventions included in the present systematic review were reported to be successful at improving at least some aspects of inhibition and/or emotion regulation skills in children with ASD. These results provide further support for the notion that these skills in children with ASD are malleable and can be trained (O'Hearn et al., 2008). In a longitudinal study looking at the long-term impact of self-regulation skills more broadly on children's life outcome, Moffitt and colleagues (2011) argued that interventions that lead to even a small improvement in self control could potentially shift the developmental trajectory of children and lead to improvements in health, wealth, and overall well-being. Therefore, targeting children with ASD with known difficulties in inhibition and emotion regulation skills has the potential to prevent the widening of achievement gaps later in life and help children get closer to their optimal developmental track.

Embracing Variability in ASD Presentation and Skills

A second overall theme that emerged throughout this manuscript is the importance of embracing variability in ASD presentation. Children with ASD present with a broad range of skills and abilities, and it is important to take this diversity into consideration when selecting a treatment course and appraising existing interventions. As results from the first study illustrate, interventions targeting inhibition and emotion regulation may not be well suited for all children with ASD. Some children may not require intervention in these areas at all, while others may

benefit from more targeted interventions. According to the identified profiles, only slightly over a third of children with ASD, those belonging to the *Broadly Affected* profile, would actually be expected to benefit from inhibition and emotion control interventions. Given that not all children with ASD will present with the same profile of needs, interventionists must take this into consideration when selecting an appropriate treatment avenue. Additionally, one must be aware that most existing interventions targeting inhibition and/or emotion regulation skills in children with ASD have only been assessed in a narrow subgroup of this neurodiverse population (i.e., mostly school-aged males with no significant delays in cognitive abilities). Therefore, existing programs may not be well suited for all children with ASD presenting with challenges in inhibition or emotion regulation.

Despite this heterogeneity in core executive and emotion control skills in ASD, only about a quarter of the included studies in the systematic review in Chapter 3 reported inclusion or exclusion criteria specific to inhibition or emotion control skills pre-intervention. Interventions focused on developing emotion regulation skills were more likely to require participants to show some challenges in managing emotion or behavioural outbursts prior to being enrolled in the intervention compared to those targeting inhibition (Conner et al., 2019; Rispoli et al., 2019; Ros-Demarize & Graziano, 2021; Singh et al., 2011; Weiss et al., 2018). Not recognizing that there is heterogeneity in ASD presentation might have influenced the results of those studies as it is likely that some of the children who participated in these interventions had no significant challenges in inhibition or emotion control to begin with.

Future research evaluating interventions targeting EF and/or emotion regulation in children with ASD need to consistently ensure that children in their programs are those presenting with challenges in the targeted area. Additionally, a person-oriented analysis of

treatment effects may also provide valuable information on who would benefit from what types of intervention. Not all children with ASD respond to treatment the same way and therefore, a person-centered approach to selecting interventions would also be warranted. Differences in treatment outcome have been well documented in early behavioural interventions for children with ASD, with some children showing large gains (e.g., Sallow & Graupner, 2005), others showing more modest improvements (e.g., Reichow, 2012; Smith et al., 2015), and others showing minimal response (e.g., Remington et al., 2007) to this type of intervention. In a study using a person-centered approach, Préfontaine and colleagues (2022) demonstrated that different profiles of impairment in children with ASD were predictive of varying magnitude and trajectories of change in adaptive functioning skills following early behavioural interventions (Préfontaine et al., 2022). Together, these results would predict that response to interventions targeting inhibition and emotion regulation will also likely vary between children with ASD, highlighting the value of a person-oriented analysis of treatment effect. Future research on interventions for children with ASD targeting inhibition and emotion regulation may also want to address the gap in the literature on interventions in those areas for children with ASD and co-occurring intellectual disability.

Useful Components of Interventions for Children with ASD

Results from the systematic review provided valuable information regarding important components for inhibition and emotion regulation interventions for children with ASD. Specifically, three types of interventions showed promising results: cognitive behavioral based interventions for emotions regulation skills, mindfulness-based interventions for inhibition and emotion regulation skills, and group-based martial arts programs targeting inhibition and emotion regulation skills. Despite varying widely, most of these promising interventions were

grounded in behavioural and cognitive theories of learning and development, demonstrating how these are likely important aspects of targeted intervention in children with ASD.

In a review article looking at important components of programs targeting EF skills in typically developing children, Diamond (2012) reported that to benefit optimally from these programs children need frequent practice (Klingberg et al., 2005), to feel continuously challenged in the task they are performing (Holmes et al., 2009; Klingberg et al., 2005) and programs must test the limits of the child's abilities (e.g., Davis et al., 2011; Diamond et al., 2007). All these components are consistent with behavioural theories of learning, which put emphasis on repetition and scaffolding, and with most cognitive theories of learning and development such as Vygotsky's Zone of Proximal Development (1987) and Bruner's Scaffolding Theory (1978). Additionally, some of the most supported interventions for children with ASD have been grounded in behavioural theories of learning, such as early intensive behavioural interventions and naturalistic developmental behavioural interventions (NDBI) (e.g., Hayward et al., 2009; Koegel & Koegel, 2006; Reichow, 2012). Therefore, it is not surprising that components of repetition, scaffolding, and test of limits were also found to be important in training programs targeting inhibition and emotion regulation skills in this population.

Cognitive strategies for learning have also been highlighted as important tools in the teaching of new skills to children (Hughes, 2011; Riccio & Gomes, 2013). These components include: (1) teaching children to notice, monitor, evaluate, and adapt their own cognitive skills to reach a goal, (2) understanding how different cognitive skills can be helpful for different situations, and (3) learning about real world applications of these skills and their importance (e.g., Galvin & Mandalis, 2009). Although cognitive interventions for children with ASD have not received the same attention as behavioural interventions, the importance of teaching children

how and why a new skill should be used has been found to be important for children with ASD in learning new skills and generalizing these skills to different contexts (Bebko & Ricciuti, 2000; Bebko et al., 2021). However, on their own, cognitive strategies have been argued to be more suited for older children and teenager (Young & Myanthi Amarasinghe, 2010), and therefore models integrating cognitive and behavioural theory may be better suited for children with varying levels of cognitive abilities such as children ASD. Results from the systematic review presented here indicated that all interventions with promising evidence were grounded in both cognitive and behavioural theories, adding to the growing support for these types of interventions in ASD (for review, see Dawson & Burner, 2011). Individuals interested in developing new programs targeting inhibition and emotion regulation in children with ASD, would likely benefit from having a behavioural and cognitive theoretical orientation.

Core EF and Emotion Regulation Skills in a Real-World Context

Lastly, a recuring theme across the entirety of this manuscript was the importance of context when examining EF and closely related constructs (e.g., self-regulation) or interventions targeting these skills. EF and SR are interrelated concepts (refer to Figure 1 and Chapter 1), and in everyday life, they overlap greatly and often co-occur simultaneously. Trying to tease apart these skills or to assess them in a controlled environment using laboratory tasks may provide limited information on how these skills present in a real-world context (Spek, 2010; Ten Eycke & Dewey, 2016). Furthermore, it is crucial to consider a child's environment when considering the applications of interventions that support the development of executive function and emotion regulation skills. Children develop within systems (e.g., family, communities, and society), and this is no different for children with ASD. Including members of a child's direct environment (i.e., caregivers and peers), along with explicitly showing how new skills can be used within a

child's immediate environment will likely promote the retention and generalization of these skills across context. With the exception of computerized cognitive training programs, most interventions presented in the systematic review showed how the new targeted skills could be used within real-world context. Additionally, most interventions with promising support included caregivers in the interventions (e.g., parent psycho-education group, parent mediated), or had typically developing peers acting as support and models. Children with ASD are known to have challenges in generalization (e.g., Fein et al., 1979, Rimland, 1964; White et al., 2007) and thus contextualizing skills being trained within the immediate everyday environment of the child and including caregivers and peers will likely support and promote the development of these skills.

Caregivers of children with ASD would likely benefit from learning more about the presentation of EF and SR challenges in autism, as they are often relied on to provide accounts of these skills during psychological assessments. Supporting parents in identifying what challenges in EF and SR may look like on a day-to-day basis, could support the accuracy and early identification of these challenges. Additionally, providing information on the links between EF and SR skills and ASD presentation to parents and professionals working with this neurodiverse group, could support the contextualization of certain behaviours and in turn foster understanding and empathy. For example, challenges in flexibility and in using adequate emotion regulation strategies to cope with the discomfort of changes in routine, may lead to behavioural outbursts in children with ASD. Some individuals may see these behavioural outbursts as attention seeking behaviours or as a child being "difficult". Understanding that children with ASD may have delays in the skills required to adequately cope with sudden change, could lead to a better understanding and appreciation for what everyday life may be like for children with ASD and why small changes may cause so much distress. Furthermore, understanding these areas of

difficulties also encourages caregivers and professionals to come up with new ways to support children with ASD.

Closing Remark

Core EF and emotion regulation skills play an important role in the presentation and development of children with ASD. Taking a person-centered approach to understanding and supporting the development of these complex skills in this heterogeneous population is critical. Interventions targeting specific components of these broader skills in children with ASD is still emerging and more research is required to establish evidence-based treatment. However, promising intervention programs are increasing, especially programs grounded in cognitive and behavioural theories, which include explicit teaching of real-world applications of these skills and involve members of a child's immediate environment (e.g., caregivers, peers). It is hoped that results from the studies included in the current manuscript can help shape and inform these types of targeted interventions for children with ASD, and in turn, support the development and growth of these incredible and diverse children.

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Appendix A

Supplemental Table 1. Indices of Fit of Models per Variance-Covariance Structure as Derived from LPA using T-Scores

Model	BLRT(p value)	AIC	BIC	Entropy
Equal variance and covariance set at zero				
One-Profile	n/a	8115.12	8143.48	1.00
Two-Profile	0.01	7843.55	7889.63	0.74
Three-Profile	**0.01**	**7724.52**	**7788.33**	**0.83**
Four-Profile	0.02	7717.85	7799.39	0.80
Five-Profile	0.04	7710.93	7810.2	0.73
Varying variance and covariance set at zero				
One-Profile	n/a	8115.12	8143.48	1.00
Two-Profile	0.01	7818.61	7888.88	0.80
Three-Profile	0.01	7716.17	7808.34	0.84
Four-Profile	0.37	7718.94	7843.02	0.80
Five-Profile	0.01	7689.2	7845.18	0.80
Varying variance and covariance				
One-Profile	n/a	7680.76	7730.39	1.00
Two-Profile	0.04	7674.04	7776.85	0.7
Three-Profile	0.05	7660.19	7816.17	0.77
Four-Profile	0.92	7673.17	7882.34	0.74
Five-Profile	0.56	7673.71	7936.05	0.74

Note: BLRT = Bootstrap likelihood ratio test; AIC = Akaike information criterion; BIC: Bayesian information criterion (BIC). The optimal model based on indices of fit is bolded.

Supplemental Table 2. Mean (SD) of BRIEF Subscales, ASD symptoms, Age, Cognitive Ability, Adaptive Skills, and Emotional/Behavioural Challenges Across the Three Profiles Constructed from T-Scores

	Broadly Affected (Profile 1)	Narrowly Affected (Profile 2)	Intact (Profile 3)	F test	η^2
n (% male)	82 (76.8%)	128 (79.7%)	46 (63.0%)	$\chi^2 = 5.18$, p = 0.075	
Age (months)	127.98 (33.67)	132.84(36.56)	116.43 (26.01)	F(2,253) = 3.95, p = 0.020	
BRIEF (T-Scores)					
Inhibit	77.09 (8.37)	60.26 (9.41)	48.20 (6.72)	**F(2,253) = 181.90, p < 0.000[abc]**	0.590
Emotion Control	74.06 (6.78)	58.94 (7.39)	43.33 (5.03)	**F(2,253) = 309.80, p < 0.000[abc]**	0.710
Working Memory	73.84 (8.64)	66.77 (9.01)	54.67 (10.42)	**F(2,253) = 64.50, p < 0.000[abc]**	0.338
Shift	80.05 (9.35)	66.34 (7.56)	49.46 (8.92)	**F(2,253) = 198.00, p < 0.000[abc]**	0.610
Cognitive Skills					
Verbal IQ*	102.01 (15.89)	100.09 (20.22)	93.93 (14.47)	F(2,242) = 3.29, p = 0.039	
Nonverbal IQ*	103.91 (14.70)	103.40 (18.21)	98.35 (17.30)	F(2,242) = 1.80, p = 0.167	
Full Scale IQ*	102.96 (14.25)	102.22 (18.58)	95.28 (16.31)	F(2,242) = 3.45, p = 0.033	
CBCL					
Anxious*	65.31 (8.70)	59.14 (8.22)	55.61 (6.01)	**F(2,206) = 19.54, p < 0.000[ab]**	0.159
Aggressive*	66.69 (7.97)	56.42 (6.17)	51.13 (2.88)	**F(2,206) = 80.64, p < 0.000[abc]**	0.439
Attention*	72.51 (10.38)	64.75 (7.47)	59.71 (7.39)	**F(2,206) = 29.44, p < 0.000[abc]**	0.222
SRS-2					
SCI	76.33 (9.31)	71.39 (9.06)	63.50 (8.88)	**F(2,182) = 19.47, p < 0.000[abc]**	0.176
RRB	79.54 (11.35)	70.41 (10.52)	58.61 (9.24)	**F(2,182) = 36.25, p < 0.000[abc]**	0.285
Adaptive Skills					
ABC*	75.29 (12.88)	78.23 (11.32)	85.37 (10.97)	**F(2,209) = 7.74, p < 0.000[bc]**	0.043
Communication*	80.37 (15.79)	82.02 (13.82)	87.90 (12.60)	F(2,208) = 2.96, p = 0.054	
Living Skills*	80.51 (15.72)	81.61 (12.62)	89.10 (10.63)	**F(2,209) = 4.57, p = 0.012[b]**	0.042
Socialization*	69.75 (11.59)	76.67 (12.26)	84.60 (13.39)	**F(2,209) = 17.18, p < 0.000[abc]**	0.141

Notes. * Winsorized data.

Post-hoc tests (p < 0.017): [a]comparing Profile 1 and Profile 2; [b] Profile 1 and Profile 3; [c] Profile 2 and Profile 3.

Appendix B

Supplemental Table 3. Medline Search Strategy

Population	**Population**	**Intervention**	**Outcome**
Children under the age of 18 years old	Autism Spectrum Disorder	Intervention/Training program	Inhibition/Executive Functioning/Emotion Regulation/Self-Regulation
MeSH	**MeSH**	**MeSH**	**MeSH**
Adolescent/ or Child/ or Child, Preschool/ or Infant/	Asperger Syndrome/ or Autism Spectrum Disorder/ or Autistic Disorder/ or Child Development Disorders, Pervasive/ or Schizophrenia, Childhood/	"Acceptance and Commitment Therapy"/ or Adolescent Health Services/ or Anger Management Therapy/ or Applied Behavior Analysis/ or Art Therapy/ or Aversive Therapy/ or Behavior Therapy/ or Biofeedback, Psychology/ or Child Care/ or Cognitive Behavioral Therapy/ or Cognitive Remediation/ or Dance Therapy/ or Desensitization, Psychologic/ or Dialectical Behavior Therapy/ or Emotion-Focused Therapy/ or Equine-Assisted Therapy/ or Family Therapy/ or Feedback, Psychological/ or Feedback, Sensory/ or Gestalt Therapy/ or Horticultural Therapy/ or Interpersonal Psychotherapy/ or Meditation/ or Mental Health Services/ or Mindfulness/ or Music Therapy/ or Neurofeedback/ or Person-Centered Psychotherapy/ or Play Therapy/ or Psychodrama/ or Psychosocial Intervention/ or Psychotherapy, Brief/ or	Emotional Regulation/ or executive Function/ or Impulsive Behavior/ or Inhibition, Psychological/ or Reactive Inhibition/ or Self-Control/

		Psychotherapy, Group/ or Psychotherapy, Multiple/ or Psychotherapy, Psychodynamic/ or Psychotherapy, Rational-Emotive/ or Psychotherapy/ or Reality Therapy/ or Relaxation Therapy/ or Role Playing/ or Schema Therapy/ or Teaching/ or Virtual Reality Exposure Therapy/	
Keywords	**Keywords**	**Keywords**	**Keywords**
(adolescen* or child* or collegiate* or elementary school* or high school* or infant* or middle school* or prepubescen* or pre-pubescen* or preschool* or pubescen* or Public school* or pupil* or teen* or toddler* or youth* or (young adj1 (person* or people))).mp.	(asd or asperger* or autis* or pervasive developmental disorder* or (child* adj2 schizophrenia)).mp.	(CBT or (cognitive-behavio?r* adj1 (treat* or therap*)) or cognitive adj1 (rehab* or training*) or cognitive remediat* therap* or Coping with Uncertainty in Everyday Situations or educat* or instruct* or interven* or (intervention adj1 (stud* or program*)) or mental exercise* or mindful* or parent-assisted intervent* or ((psychosocial or psycho-social) adj3 (interven* or therap* or rehab*)) or psychotherap* or psycho-therap* or (school-based adj1 (program* or mindful*)) or set-shifting improvement task* or (self-monitor* adj1 (program* or treat*)) or ((stress or anger) adj1 (managem*or program*)) or Structured TEACCHing or teach* or therap* or train* or treat* or yoga-based therap*).mp.	(behavio?r* flexbilit* or Behavio?r* Flexibility Rating Scale or (Behavio?r Rating Inventory adj1 Executive Function*) or (cognitive adj1 (dysfunc* or flexibilit*)) or Color-Word Interference test or (delay* adj2 gratification) or ((emotion* or impuls*) adj3 (control* or function* or regulat* or manag*)) or (executive adj (abilit* or function* or dysfunction* or dys-function*)) or impulse control* or inhibit* or interference control or regulat* or response inhibit* or (self* adj3 (control* or regulat* or monitor*)) or self-regulat* or Walk Don't Walk test or Wisconsin Card sort* or Stroop test*).mp.

Supplemental Table 4. Quality Indicator Assessment for Group Design

	Participants	IV	Com. Con.	DV	Link	Stat	RA	IOA	Blind Rater	Fidelity	Attrition	Gen/ Main	ES	SV
Acero-Ferrero et al. (2017)	U	U	U	U	A	U	N	N	N	N	N	E	E	N
Chan et al., (2013)	H	A	H	H	H	H	E	N	E	N	E	E	E	E
Chen et al., (2020)	A	U	A	A	A	A	E	N	N	N	N	E	N	N
Chu et al., (2020)	A	U	U	A	A	U	N	N	N	N	N	N	E	N
Conners et al., (2019)	A	H	U	A	H	A	N	N	N	E	E	N	E	E
Fisher & Happé (2005)	U	U	U	A	A	U	E	N	E	E	N	N	N	N
Greco & De Ronzi (2020)	H	A	A	H	H	H	E	N	N	N	E	N	E	E
Juliano et al., (2020)	A	H	U	H	H	A	N	N	N	N	E	N	E	N
Macoun et al., (2020)	H	A	A	A	A	A	E	N	E	E	E	N	E	E
Nowell et al., (2019)	H	H	A	A	A	U	E	E	E	E	E	E	E	E
Pan et al., (2017)	A	H	A	A	A	A	E	N	N	E	N	E	E	N
Phung & Goldberg (2019)	H	A	A	H	H	H	E	N	N	E	N	E	E	N
Ros-Demarize & Graziano (2021)	A	H	U	H	H	A	N	E	N	E	E	E	E	E

Scarpa & Reyes (2011)	A	H	A	A	A	A	E	N	N	N	E	N	E	N
Sofronoff et al., (2007)	H	H	A	H	H	H	E	N	N	N	E	E	N	E
Swain et al., (2019)	A	H	U	A	A	A	N	N	N	E	N	N	N	N
Tanksale et al., (2021)	H	H	A	H	H	H	E	N	N	N	E	E	N	E
Thomson et al., (2015)	H	H	U	H	H	A	N	N	E	E	E	N	N	E
Weiss et al., (2018)	H	H	A	H	H	H	E	E	N	E	E	E	E	E
Yerys et al., (2019)	H	A	A	H	H	U	E	N	N	E	E	N	E	E

Note. View Reichow et al., (2008) for description of each quality rating items and rating scale. IV: independent variable, Com. Con.: comparison condition, DV: dependent variable, Stat: statistical testing, RA: random assignment, IOA: interobserver agreement, Gen/Main: generalization/maintenance, ES: effect size, SV: social validity, H: high, A: acceptable, U: unacceptable, E: evidence, N: no evidence.

Supplemental Table 5. Quality Indicator Assessment for Single Case Design

	Participants	IV	DV	Baseline	Vis. Analysis	Exp. Cont.	IOA	Kappa	Fidelity	Blind raters	Gen/Main	SV
Rispoli et al., (2019)	H	A	A	U	U	A	N	N	E	N	E	E
Singh et al., (2011)	A	H	H	H	H	A	E	N	N	N	E	E

Note. View Reichow et al., (2008) for description of each quality rating items and rating scale. IV: independent variable, DV: dependent variable, Vis. Analysis: visual analysis, Exp. Cont.: experimental control, IOA: interobserver agreement, Gen/Main: generalization/maintenance, ES: effect size, SV: social validity, H: high, A: acceptable, U: unacceptable, E: evidence, N: no evidence.

Supplemental Table 6. Risk of Bias Assessment Based on the Downs and Black Checklist

	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26
Acero-Ferrero et al., (2017)	0	0	0	0	0	0	1	0	0	0	0	0	0
Chan et al., (2013)	0	1	0	1	1	0	1	0	0	1	1	0	1
Chen et al., (2020)	0	0	0	0	1	0	1	1	1	1	0	0	0
Chu et al., (2020)	0	0	0	1	0	0	0	1	1	0	0	0	0
Conner et al., (2019)	0	0	0	1	1	1	1	1	1	0	0	0	0
Fisher & Happé (2005)	0	0	0	0	0	0	1	1	1	1	0	0	0
Greco & De Ronzi (2020)	0	0	0	1	1	0	1	1	1	1	1	0	1
Juliano et al., (2020)	0	0	0	1	1	0	1	0	1	0	0	0	1
Macoun et al., (2020)	0	0	0	1	1	1	1	0	0	1	0	0	1
Nowell et al., (2019)	0	1	1	1	0	1	1	0	0	1	0	0	1
Pan et al., (2017)	0	0	0	1	1	0	1	1	1	1	0	0	0
Phung & Goldberg (2019)	0	0	0	0	1	0	1	1	0	1	0	0	0
Rispoli et al., (2019)	0	0	0	1	0	1	1	0	1	0	0	0	0
Ros-Demarize & Graziano (2021)	0	0	1	1	1	1	1	0	0	0	0	0	1
Scarpa & Reyes (2011)	0	0	1	0	1	0	1	0	0	1	0	0	0
Singh et al., (2011)	0	0	1	1	1	0	1	0	0	0	0	1	1
Sofronoff et al., (2007)	0	0	1	1	1	0	1	0	0	1	0	0	1
Swain et al., (2019)	0	0	1	0	1	1	1	0	0	0	0	0	0
Tanksale et al., (2021)	0	0	1	1	1	1	1	0	0	1	0	0	1
Thomson et al., (2015)	0	1	1	1	1	1	1	0	0	0	0	0	1
Weiss et al., (2018)	0	0	1	1	1	1	1	0	1	1	0	1	1
Yerys et al., (2019)	0	0	1	1	1	0	1	0	0	0	0	0	1

Notes. View Downs & Black (1998) for information on each individual questions and rating scale. 1= Yes; 0 = No or unable to determine