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To cite this article:

Irvan, R. and Tsapali, M. (2020) The Role of Inhibitory Control in Achievement in Early Childhood Education, *Cambridge Educational Research e-Journal*, Volume 7, pp. 168-190. DOI: <https://doi.org/10.17863/CAM.58319>



Published online: 1st November 2020



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The Role of Inhibitory Control in Achievement in Early Childhood Education

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Abstract

This review paper explores the relationship between academic achievement in early childhood education and inhibitory control, namely students' ability to regulate behaviour, emotions and thoughts to complete specific tasks. The majority of research in this area has focused on achievement in mathematics, literacy or a combination of both. Despite the recent uptake of 'whole child' focused education initiatives, few studies explore social-emotional learning, or all three areas collectively, a gap this paper aims to address. This paper offers a comprehensive review of previous research on inhibitory control and achievement to highlight areas of focus for future research and provide a theoretical basis for study design. The review draws on articles published in the English language and systematically compares research methodologies to elucidate the choices made by researchers. The findings indicated correlations between inhibitory control and the three areas of early childhood education, mathematics, literacy and social-emotional learning, although causation is not established. Hot inhibitory control, involving emotion or an external motivator, was found to be closely related to social-emotional learning and cool inhibitory control, limited emotional and an abstract motivator, with mathematics and literacy. Notably, emergent literacy varied by the language spoken by students. A look at the measures and samples used revealed that purposefully employing inhibitory control measures that align with real-world classroom activities may provide greater insight into the relationship between achievement and inhibitory control. The findings of this paper pose significant implications for research, policy and practice, especially with the recent uptake of social-emotional learning by education programs, as they reveal how inhibitory control relates to students' ability to thrive in early childhood education settings. In the light of these findings, it is important for educators and researchers to consider how inhibitory control may in itself, be considered a goal of early childhood education.

Resumen

Este artículo de revisión explora la relación entre el logro académico en la educación infantil y el control inhibitorio, es decir, la capacidad del alumno para regular su comportamiento, emociones y pensamientos para completar tareas específicas. La mayor parte de la investigación en esta área se ha centrado en el rendimiento en matemáticas, alfabetización o una combinación de ambos. A pesar de la reciente adopción de iniciativas de educación centradas en el "niño completo", pocos estudios exploran el aprendizaje socioemocional, o las tres áreas de manera colectiva, una brecha que este documento pretende abordar. Este artículo ofrece una revisión exhaustiva de investigaciones previas sobre el control inhibitorio y los logros para resaltar áreas de enfoque para investigaciones futuras y proporcionar una base teórica para el diseño del estudio. La revisión se basa en artículos publicados en inglés y compara sistemáticamente las metodologías de investigación para dilucidar las elecciones realizadas por los investigadores. Los hallazgos indicaron correlaciones entre el control inhibitorio y las tres áreas de educación infantil: matemáticas, alfabetización y aprendizaje socioemocional, aunque no se ha establecido la causalidad. Se encontró que el control inhibitorio caliente, que involucra emoción o un motivador externo, está estrechamente relacionado con el aprendizaje socioemocional, mientras que el control inhibitorio frío, un motivador emocional limitado y abstracto, con las matemáticas y la alfabetización.

Article History

Submitted: 26th

March 2020

Accepted: (date)

Keywords

Early Childhood Education, Executive Functions, Inhibitory Control, Academic Achievement, Social-Emotional Learning

Palabras Clave

Educación Infantil, Funciones Ejecutivas, Control inhibitorio, Logro académico, Aprendizaje socioemocional

Notablemente, la alfabetización emergente varió según el idioma hablado por los estudiantes. Una mirada a las medidas y muestras utilizadas reveló que el empleo intencional de medidas de control inhibitorio que se alineen con las actividades del mundo real en el aula puede proporcionar una mayor comprensión de la relación entre el rendimiento y el control inhibitorio. Los hallazgos de este artículo tienen implicaciones significativas para la investigación, las políticas educativas y la práctica, especialmente con la reciente adopción del aprendizaje socioemocional por parte de los programas educativos, ya que revelan cómo el control inhibitorio se relaciona con la capacidad de los estudiantes para progresar en entornos de educación infantil. A la luz de estos hallazgos, es importante que los educadores e investigadores consideren cómo el control inhibitorio puede, en sí mismo, ser considerado un objetivo de la educación infantil.

الملخص:

يشرح هذا البحث الاستعراضي العلاقة بين التحصيل الأكاديمي في مرحلة تعليم الأطفال في سن مبكرة و التحكم التثبيطي، أي قدرة الطالب على ضبط السلوك والعواطف والأفكار لإنجاز مهام معينة. تركز غالبية الأبحاث في هذا المجال على التحصيل العلمي للطلاب في الرياضيات أو الإلمام بالكتابة والقراءة أو المزج بين الإثنين. على الرغم من ظهور الكثير من المبادرات التي تدعو إلى تعليم شامل يغطي كافة النواحي المعرفية والاجتماعية وغيرها، إلا أن القليل من الدراسات تدرس التعلم العاطفي الاجتماعي، أو المجالات الثلاثة مجتمعة، وهي الفجوة التي تهدف هذه الدراسة إلى معالجتها. يقدم هذا البحث دراسة شاملة لأبحاث سابقة عن التحكم التثبيطي و التحصيل العلمي لتسليط الضوء على المجالات الواجب التركيز عليها في الأبحاث المستقبلية وتوفير أساس نظري للتصميم الدراسي. يستند هذا الاستعراض البحثي على مقالات تم نشرها باللغة الإنكليزية ويقارن طرائق ومنهجيات البحث بشكل منهجي لتوضيح الاختيارات التي قام بها الباحثون. أشارت النتائج إلى وجود صلة بين التحكم التثبيطي والمجالات الثلاثة لمرحلة تعليم الأطفال في سن مبكرة، الرياضيات، الإلمام بالكتابة والقراءة والتعلم العاطفي الاجتماعي، علماً أنه لم يتم تحديد العلاقة السببية أو إثباتها. إكتشف بأن التحكم التثبيطي الحار، الذي يتضمن عاطفة أو محفز خارجي، له صلة وثيقة بالتعلم العاطفي الاجتماعي والتحكم التثبيطي البارد، الذي يتضمن محفز عاطفي محدود و مجرد، له صلة وثيقة مع الرياضيات و الإلمام بالكتابة و القراءة. وتجدر الإشارة إلى أن تباين الإلمام بالقراءة والكتابة الناشئة يعود لإختلاف اللغة التي يتحدث بها الطلاب. وبالنظر إلى المقاييس والنماذج المستخدمة يتبين لنا أن الإستخدام الهادف لمقاييس التحكم التثبيطي التي تتوافق مع الأنشطة الصفية المطابقة لعالم الواقع يمكنها أن توفر رؤية أعمق للعلاقة بين التحصيل العلمي والتحكم التثبيطي. إن نتائج هذا البحث تطرح إنعكاسات وتأثيرات على البحث العلمي والسياسة والممارسة، لا سيما مع الإقبال الأخير للبرامج التعليمية على التعلم العاطفي الاجتماعي. كما وتكشف هذه النتائج كيفية ارتباط التحكم التثبيطي الوثيق بقدرة الطلاب على الازدهار في بيئات التعليم في مرحلة الطفولة المبكرة. في ضوء هذه النتائج، من المهم للمعلمين والباحثين أن ينظروا في إمكانية اعتبار التحكم التثبيطي بحد ذاته هدف من أهداف التعليم في مرحلة الطفولة المبكرة.

الكلمات المفتاحية
الأطفال تعليم مرحلة
مهام، مبكرة سن في
التحكم، تنفيذية
التحصيل، التثبيطي
التعلم، العلمي
الاجتماعي العاطفي.

Introduction

Researchers and policymakers around the world believe early childhood education is essential for children's health, wellbeing and intellectual development (Ajayi, 2008; Council of the European Union, 2019; Tickell, 2011; UNICEF, 2019; Zhou, 2011). There is widespread evidence to suggest children participating in preschool programmes benefit cognitively and develop the tools they need to succeed in future schooling and in later life (Boocock, 1995; Tickell, 2011; UNICEF, 2019). Early childhood is an important time in the development of executive functions and the prefrontal cortex (Bierman & Motamedi, 2015; Diamond, 2002; Garon, Bryson, & Smith, 2008). *Executive functions* is a term used to describe the processes of the prefrontal cortex that help people achieve goals and is often referred to as *inhibitory control*, *working memory*, and *cognitive flexibility* (Best, Miller, & Jones, 2009; Diamond, 2013). Inhibitory control is the process by which individuals suppress stimuli and control behavioural responses and is supported by the prefrontal cortex (Gruber & Goschke, 2004; Zelazo & Müller, 2002). An example of inhibitory control is resisting the temptation to overeat (Diamond, 2012). According to Diamond (2002), inhibitory control

comes into effect around the age of 1 and develops over the next few years. Working memory, described as the ability to hold information in one's mind and manipulate it, is often thought to coexist with inhibitory control (Diamond, 2013). Working memory is manifested, for example, in the ability to learn a sequence of numbers and then being able to recall them in order (Raver & Blair, 2016). Cognitive flexibility utilises working memory and inhibitory control and develops in children around 7 to 9 years of age (Diamond 2013; Garon *et al.*, 2008). The ability to change perspectives or how we think about something, such as thinking 'outside the box' to solve a problem, is a function of cognitive flexibility (Diamond, 2013). The Center on the Developing Child at Harvard University (2011) considers these three components to be building blocks for more complex executive functions that develop later in life. Inhibitory control develops mostly during the early childhood education years and changes less later in life while working memory develops more gradually over time (Best & Miller, 2010). This review focuses on inhibitory control instead of cognitive flexibility since inhibitory control develops during the period that children are in preschool classrooms. While working memory is an important element of development, inhibitory control is particularly crucial for young children growing up and learning with constant distractions vying for their attention.

Based on the available literature, there has been much research into the relationship between inhibitory control, and the various distinct skills early childhood education aims to foster, less attention has been paid by scholars to a holistic exploration of the relationship between the two. Through the analysis of existing literature, we explored the role of inhibitory control in achievement in early childhood education. Previous researchers have focused on mathematics and literacy, while largely ignoring the importance of the role of social-emotional learning. While, Allan, Hume, Allan, Farrington, and Lonigan's (2014) meta-analysis consolidates past findings and serves as a reference for future research, it does not acknowledge the role social-emotional learning plays in the relations between inhibitory control and academic skills in young children. Acquiring early academic skills, and developing inhibitory control is key for children to have a successful transition into more structured compulsory schooling (Allan *et al.*, 2014) and in addition, social-emotional learning should be taken into consideration. Social-emotional learning and achievement in early childhood education are inextricably linked and as Frey, Fisher and Smith (2019) point out "all learning is social and emotional" (p.17), a statement that is supported and explored in relation to inhibitory control. First, we sought out information specifying the desired outcomes for early childhood education around the world to gain an understanding of the similarities across countries and cultures to establish an international perspective. However, the search was limited to papers written in the English language and thus, not fully representative of the global research terrain. Next, we sifted through constructs that included inhibitory control and its relationship with early learning goals. Then, our focus narrowed to analysing studies on inhibitory control and early childhood. We synthesised studies, meta-analyses, and systematic reviews, establishing previous research practices in measuring inhibitory control, key findings, and conflicting views. We set up a spreadsheet to compare varying views on early childhood education and different ideas concerning inhibitory control in the available literature. Some studies provided an in-depth look at inhibitory control and achievement while others addressed

inhibitory control as one aspect of their work. We initially sampled 100 studies and, after narrowing down through specific exclusion criteria related to the focus of the study, the age group and the year of publication, we evaluated 15 studies in depth (see Table 1 in the Appendix for an overview of the studies). For this paper, we report on work that offers deeper insight into the role of inhibitory control in early childhood. The areas of early childhood education we focus on are early mathematics, emergent literacy, and social-emotional learning.

In order to establish a clear multi-cultural and international definition of what early childhood education aims to accomplish, research from around the world is included. Demographic information from the studies is highlighted, when available, to give readers insight into the students represented in the literature. In an effort to inform future research, we present an overview of current research on inhibitory control, document common measures of inhibitory control and consider the implications of findings for classroom practices. In this paper, we explore the role of inhibitory control in early childhood education and discuss how it relates to the goals of early mathematics, emerging literacy and social-emotional learning.

Defining Achievement in Early Childhood Education

Early childhood education is commonly referred to as any schooling before the compulsory age, which varies by country, and is known variously as nursery school, pre-kindergarten, and preschool. For the scope of this paper, we focus on the desired outcomes of early childhood education as opposed to outlining a philosophical debate on its best practices. To explore the connections between inhibitory control and achievement, we establish a global perspective on what the desired outcomes are. Finally, the subcategories, early mathematics, emergent literacy and social-emotional learning, often listed as part of the trending holistic view, are outlined below.

Before discussing the landscape of early childhood education, it is important to acknowledge the theories and scholars who have influenced current practices. Educational and developmental psychology researchers have long debated theories, policy frameworks, proper measures and desired outcomes regarding early childhood education. Comenius' and Fröbel's focus on the whole child, Dewey's and Weikart's learning by doing, and Piaget's child-centred approach, feature prominently when exploring the foundations of early childhood education (Peltzman, 1998). These pioneers, among many others, believed traditional academic subjects such as mathematics and literacy were not the most important elements of early childhood education. Kamerman (2007) points out a focus on the whole child and overall child development as an educational goal garnered from UNESCO in 1961 and 1974, which summarised the viewpoint of 65 and 67 countries, respectively. Recent policies and practices support a holistic view of early childhood education (Kamerman, 2007; Nuttall, 2003; Raikes, 2017; Tickell, 2011). Preparing students for the next level of education is a primary goal for early childhood education (Ajayi, 2008; Council of the European Union, 2019; UNICEF, 2019). Many authors state early mathematics understanding and numerical knowledge as learning goals (Ajayi, 2008; Tickell, 2011; Wylie & Thompson, 2003). Emerging literacy skills including language acquisition,

speaking, listening and phoneme awareness, are also common themes in the educational goals for young children (Ajayi, 2008; Rohde, 2015; Tickell, 2011; Wylie & Thompson, 2003). Social-emotional learning outcomes such as empathy-building, compassion, teamwork, and mental well-being are becoming more common in the literature on desired outcomes for early childhood education (Ajayi, 2008; Council of the European Union, 2019; Bierman & Motamedi, 2015; Ministry of Education, 2010; National Association for the Education of Young Children, 2018; Tickell, 2011; Wylie & Thompson, 2003).

Social-emotional learning is described in terms of emotional awareness, perspective taking, constructive conflict resolution, peer relations, and self-awareness (Wolf & McCoy, 2019). Social-emotional learning is included as a goal of early childhood education along with the more traditional academic goals of mathematics and literacy to prepare early learners for the next stage of learning. Early childhood is primetime for the acquisition of different kinds of skills and knowledge (Hendrick & Weissman, 1996) and should aim to educate the whole child, fostering the social-emotional development of children who can think, feel, and act (Miller, 2010). In this paper, we define achievement in early childhood education as achievement in mathematics, emergent literacy, and social-emotional learning.

Defining Inhibitory Control

Inhibitory control is commonly referenced as an aspect of executive functions, effortful control or self-regulation and previous research outlines the complex web of terms relating to inhibitory control (Allan *et al.*, 2014; Rhoades *et al.*; Tiego, Testa, Bellgrove, Pantelis, & Whittle, 2018). To avoid any miscommunication or misleading use of terminology, and because of the commonalities between the terms, for the remainder of the paper, we will use the phrase inhibitory control to refer to any term relating to the suppression of seemingly automatic actions in order to reach a desired goal.

Inhibitory control, along with working memory and cognitive flexibility, is one of the core executive functions (Center on the Developing Child at Harvard University, 2011; Diamond, 2013). Previous studies have explored executive functions in tandem with each other and some researchers focus on executive functions as a unitary construct rather than exploring its individual components (Garon *et al.*, 2008; Wolf & McCoy, 2019). As inhibitory control is considered a building block to more complex executive functions and because it is believed to develop mostly during the years students are enrolled in early childhood education, we chose it as our focus for this paper. According to Diamond (2013), inhibitory control, especially challenging for young children, is the ability to regulate behaviour, emotions or thoughts to nullify the effect of external interference or internal susceptibility for distraction to do what is needed. Rhoades, Greenber and Domitrovich (2009) describe inhibitory control as a cognitive-related ability that is valuable for children in early educational settings. The focus on measuring inhibitory control in young children is in line with the idea that standard executive functioning tasks and the young brain develop around the same time (Gagne & Saudino, 2016). Diamond (1990) posits that inhibitory control

increases along with the maturation of the prefrontal cortex. It is thought that the right inferior frontal gyrus area of the prefrontal cortex performs inhibitory control over other parts of the brain (Munakata *et al.*, 2011). The orbitofrontal region of the prefrontal cortex is said to be related to hot, involving emotion or an external motivator, and the dorsolateral related to cool, abstract or neutral context and no external motivator, aspects of inhibitory control (Zelazo & Müller, 2002).

Garon *et al.*, (2008) equate improvements in inhibitory control with the maturation of the prefrontal cortex in the early years, referring to it as response inhibition. The supplementary motor area and the dorsolateral prefrontal cortex are not fully mature in 1-year-olds, and although significant connections are made in this time, inhibitory control is not fully developed (Diamond, 1990). Since inhibitory control develops along with various regions in the brain, studies of inhibitory control and young children are more common than studies on adolescents and adults. A challenge to performing longitudinal studies on inhibitory control is that development of the prefrontal cortex does not accelerate until adolescence and is not fully mature until the mid-twenties (Arain *et al.*, 2013). The construct of inhibitory control is more nuanced than the scope of this paper allows. For a more in-depth examination of the intricacies of inhibitory control, Munakata *et al.* (2011) offer a framework through a neuroscience lens. In this paper, we focus on how inhibitory control may uniquely affect early childhood academic achievement.

Measuring Inhibitory Control

Inhibitory control tasks measure the capacity of a person to overcome a conditioned or dominant behavioural reaction and choose a more adaptive goal-oriented behaviour (Diamond, 2013). There is no consensus on how to best measure inhibitory control and researchers have discussed the complexities involved. When examining the link between academic skills and inhibitory control the measures used influence findings. Some studies focus on the differences between hot, involving emotion affect or an external motivator, and cool, abstract or neutral context and no external motivator, inhibitory control (Allan *et al.*, 2014; Di Norcia, Pecora, Bombi, Baumgartner, & Laghi, 2015). Allan *et al.*'s (2014) meta-analysis suggests that academic skill measures had a significantly stronger association with behaviour task measures of inhibitory control than reported measures. Behaviour tasks and teacher reports were shown to be more reliable measurements of children's inhibitory control than parent reports (Allan *et al.*, 2014). The majority of studies mentioned in this paper utilised behaviour tasks to measure inhibitory control. Table 1 is included in the Appendix for readers who wish to have more insight into the studies and measures referenced in this paper.

Petersen, Hoyniak, McQuillan, Bates and Staples (2016) warn of the challenges in measuring the development of inhibitory control and its behavioural manifestations over time. They argue that there is no way to be certain that the same thing is being measured longitudinally. Petersen *et al.* (2016) advised that researchers should take a theoretically and empirically informed approach when committing to longitudinal studies to gain a better understanding of the developmental perspective of inhibitory control as it relates to specific outcomes. Along the same lines, Ahmed,

Tang, Waters and Davis-Kean (2019) recently published a longitudinal study on executive functions and found no significant relationships between inhibitory control in early childhood and inhibitory control in later years. This indicates that the measures themselves may have captured distinct cognitive properties during these two major developmental stages and points to measurement variance over time. Based on these studies, it seems that measuring inhibitory control over longer periods is complicated. The remainder of this paper will focus on measurements taken in children's early years, due to the developmental nature of inhibitory control and the challenges of correlating changes over long periods of time.

Inhibitory Control and Early Childhood Education

The early childhood education years are important for the development of effective learning habits and inhibitory control. Allan *et al.*, (2014) performed a meta-analysis that explored the effect of inhibitory control on maths and literacy skills in young children. The conclusions drawn from their meta-analysis indicate a correlational relationship between inhibitory control and academic skills, more so with early mathematics than emergent literacy skills. While their findings point to a clear connection between inhibitory control and academic skills, it is not known whether increased inhibitory control leads to increased academic ability, vice versa, or if they are both regulated by the same neural substrates. In this paper, we bring in research performed since their analysis and also include studies looking at social-emotional learning and inhibitory control. Further research is needed to explore the relationship and possible directional causation.

This paper considers social-emotional learning formative in the foundation for positive learning and is central for student development, alongside and equal to the importance of early mathematics and emergent literacy and like Frey *et al.* (2019) we consider it front and centre, rather than an afterthought. Furthermore, it is becoming one of the most common areas of focus in early childhood education (European Commission, 2019). The following sections focus on studies examining early childhood measures of inhibitory control in relation to specific areas of early mathematics, emergent literacy, and social-emotional learning.

Early Mathematics

Mathematics can be a daunting subject for many students, and it is important for children to have positive mathematical experiences at a young age if they are to continue to be engaged and inspired learners. Early mathematics can take various forms including counting, recognising shapes, and spatial awareness. Inhibitory control is required for students to approach maths tasks in general because of the need to follow directions and follow a line of reasoning (Blair & Razza, 2007; Son, Choi, & Kwon, 2019). McClelland *et al.* (2014) sampled preschool children from the Pacific Northwest USA, using the Day/Night and the Simon Says tasks. Their predominantly homogeneously white population sample showed that inhibitory control tasks related to increased early mathematics scores and further indicated that increased inhibitory control scores predicted maths scores from the fall to the spring of a school year. In a similarly conducted study published

a year later, Ng, Tamis-LeMonda, Yoshikawa and Sze (2015) concurrently and longitudinally measured inhibitory control and maths skills of children from a large urban city in the USA. They sampled a diverse population to explore how inhibitory control and early maths skills are related in regard to race and ethnic groups. Ng *et al.* (2015) compared inhibitory control and early math skills at age 4 with age 4 and 6 early maths skills using the Peg Tapping task. The strong positive correlation they observed is in line with previous findings and they also added to research on inhibitory control by discovering that Chinese children scored higher than other ethnic groups on inhibitory measures and maths skills assessments. Since the Chinese children's scores were higher in both the early and later testing it is not known if there was another confounding variable that elevated each of these measures, if one factor influences the other or if they both develop at the same time. Son *et al.* (2019) built upon this research and added to the conversation of possible differences in children's early academic abilities between ethnic groups and the impact of inhibitory control on math measures over time. They found a reciprocal association between inhibitory control and early maths skills, for children of varying ethnicities, over a 3-year period. They assessed inhibitory control using the Pencil Tap task and in keeping with previous research, they found children who showed higher inhibitory control had more advanced maths skills.

Harvey and Miller (2017) conducted a study using an ethnically diverse population. In addition, the sample was composed of dual language learners, with 41% having a primary language other than English spoken at home, and 11% of the population having a developmental delay certification. They used the Flanker Inhibitory Control test of inhibitory control and found early math skills to be positively correlated with inhibitory control across ethnicities. Students with developmental delay certifications showed no significant differences in scores on any of the measures. DeFlorio *et al.* (2019) also studied a diverse group of 2 to 3-year-old children, from an undisclosed location in the USA, almost half of whom spoke Spanish or were bilingual. Their study contributed new findings to the field and set itself apart from previous studies by using a randomised control trial to evaluate two early maths interventions and explore a possible causal relationship between inhibitory control and maths skills. They used The Gift Wrap, Waiting for Bow, Bear/Dragon, and Day/Night tasks to measure inhibitory control. Their use of multiple measures allowed them to explore hot and cool inhibitory control. They found that early math skills measures predicted later cool inhibitory control measures. The relationship between hot inhibitory control and maths skills was bidirectional and the relation between cool inhibitory control and maths skills was unidirectional. Maths skills predicted performance on the Bear/Dragon task from the beginning of preschool to the end of preschool but only predicted performance on the Day/Night task for the preschool year. They surmise that this result may be due to the Bear/Dragon task being easier and more accessible to 3-year-olds. This raises the question of how inhibitory control is being measured and whether there is an ideal or standard way to approach the task.

Inhibitory control measures positively correlate with measures of early mathematics skills (Allan *et al.*, 2014; DeFlorio *et al.*, 2019; Harvey & Miller, 2017; McClelland *et al.*, 2014; Ng *et al.*, 2015; Son, *et al.*, 2019). Son, *et al.* (2019) reported the same correlations of inhibitory and maths

skills in bilingual students and those with developmental delays as monolinguals and students without developmental delays. Recent studies have purposefully focused on sampling a diverse range of students and Ng *et al.* (2015) found a sample of Chinese students in the USA with higher levels of inhibitory control and maths skills than other ethnicities. As recommended by Son *et al.* (2019), future researchers should consider including multiple measures of inhibitory control and analysing any differences that arise to ensure testing outcomes are more reliable. DeFlorio *et al.*'s (2019) look into the complexities of inhibitory control concluded that early maths skills measures predicted later cool inhibitory control measures but not hot inhibitory measures. It appears that specific inhibitory control measures provide varying results and cool inhibitory control tasks are more closely related to the demands of early mathematics. The positive correlation between early mathematical skills and inhibitory control is reported in students of various ethnicities and ability levels. The relationship may be because the development of skills that are helpful in early mathematics, such as perseverance and sequential problem-solving, utilise children's inhibitory control.

Emergent Literacy

Emergent literacy includes the skills of speaking, listening, reading, and writing (Rohde, 2015). The development of these skills occurs during a crucial time of brain development and needs to be nurtured from infancy (Tickell, 2011). It has previously been proposed that inhibitory control can help children manage their behaviours in a goal-oriented way by suppressing distracting actions and thoughts and in turn facilitate learning vocabulary from interactions with their environments (Diamond, 2013). Researchers around the world have explored the relationship between inhibitory control and emergent literacy in multiple languages with mostly similar results.

Jabłoński (2013) study on Polish preschool children between the ages of 3 and 5 measured inhibitory control using the Children Card Sort task consisting of four levels of assessment progressing in difficulty. Students were separated into 24 groups based on their age to explore the developmental relationship between literacy and inhibitory control. Overall, younger children scored lower than older children in phase three of the Children Card Sort task, confirming a link between age and inhibitory control. Their results indicate that literacy abilities were related to age and also suggest that children develop literacy skills at different times. Jabłoński (2013) added another element to their study by clustering students by differing levels of literacy mastery. When student data was organised into clusters based on literacy scores a developmental relationship between the early stages of written speech with lower levels of inhibitory control and the later stages with more inhibitory control was observed. The results do not point to a causal developmental relationship between emergent literacy and inhibitory control scores; however, they offer a starting point for future studies focused on stages of literacy development. The developmental relationship between inhibitory control and emergent literacy could be due to the relationship between the prefrontal cortex and areas of the brain related to language acquisition (Gruber & Goschke, 2004).

Peredo, Owen, Rojas, and Caughy (2015) explored the relationship between inhibitory control and children's vocabulary in Spanish speaking children in a metropolitan area in the southwestern USA. They used the Snack Delay, Wrapped Gift and Forbidden Toy tasks to measure inhibitory control at the ages of 2 and 3. Their findings linked growth in inhibitory control to lexical diversity. They found that faster growth in inhibitory control skills between the ages of 2 and 3 was related to a richer vocabulary at age 2. Ekerim and Selcuck's (2018) findings lend support to these claims as they also found a correlation; children with initial higher inhibitory control skills had better vocabulary knowledge than those with lower inhibitory control skills at the initial and subsequent points of data gathering. Ekerim and Selcuck (2018) studied Turkish pre-schoolers from five different cities in Turkey using the Two-Part Peg Tapping task to measure inhibitory control once at around age 4 and again at around age 5. The first measure of inhibitory control had a positive correlation with vocabulary knowledge scores at both times of measurement. Although Peredo *et al.* (2015) and Ekerim and Selcuck (2018) studied children of different ages and in different countries, both studies found a connection between inhibitory control and vocabulary knowledge over time.

Bohlmann and Downder (2016) explored the relationship between inhibitory control, termed self-regulation, and emergent language and literacy skills in 3 and 4-year-olds across eight states in the USA. They compared children's emergent literacy and inhibitory control, using the Pencil Tap task, in fall and compared the results with measures from spring. Inhibitory control was significantly related to emergent literacy outcomes. They found higher inhibitory control measures correlated with higher emergent literacy scores at both times in the study. Similarly, Son *et al.* (2019) found that inhibitory skills, using the Pencil Tap task predicted subsequent reading skills in an ethnically diverse sample in the USA. Much of the research being carried out is complementary and follows similar research designs, however, De Franchis, Usai, Viterbori and Traverso's (2017) findings on relationships between inhibitory control and Italian emergent literacy were contradictory to the other studies mentioned. They found that inhibitory control did not predict future literacy performance. They compared measures of Italian children's preschool inhibitory control, using the Circle Drawing task, to their literacy achievement at ages 6 and 8. The difference in findings could be due to child development over time as De Franchis *et al.* (2017) performed their subsequent measurements at a slightly later age than previous research. Also, it may be because of the languages with which each of the studies was related as the Italian and English languages require the use of different lexical and sublexical strategies (De Franchis *et al.*, 2017). Their work serves as a starting point for future research to compare students that speak different languages in the same study.

Inhibitory control is correlated with higher vocabulary knowledge and contributes to language development in children (Ekerim & Selcuk, 2018; Peredo *et al.*, 2015). Jabłoński's (2013) results suggest a relationship between the developmental timelines of inhibitory control and emergent literacy differences. The more recent studies into inhibitory control and emergent literacy did not report on the relationship with cool inhibitory control that Allan *et al.* (2014) found in their meta-analysis. Similar to findings concerning early mathematics, researchers found that inhibitory

control measures positively correlate with emergent literacy measures (Jabłoński, 2013; Son *et al.*, 2019). The work being done in relation to inhibitory control and emergent literacy is more representative of children of various cultures than research involving early mathematics. This may perhaps be due to emergent literacy being related to the language spoken, which can vary, and mathematics findings being more universal across cultures.

Social-Emotional Learning

A preschool setting is often the first-time children are part of a larger structured group with peers of their age. During these formative years between the ages of 3 and 6 children become more able to inhibit reactive impulses and take responsibility for managing their own behaviour (Bierman & Motamedi, 2015). Becoming aware of other people's emotional experiences is a vital developmental task for young children (LaBounty, Bosse, Savicki, King, & Eisenstat, 2017). Children with more advanced emotional regulation skills are better prepared to handle the change in learning environments between preschool and primary school compared to those lacking emotional regulation skills (Graziano, Reavis, Keane, & Calkins, 2007). When researching social-emotional learning some researchers observed students taking part in inhibitory control tasks and others used measures reported by teachers or caretakers.

LaBounty *et al.* (2017) sampled 3 and 4-year-olds in Portland, USA using the Children's Behaviour Questionnaire–Short Form Inhibitory Control Subscale. They found inhibitory control to be positively correlated with understanding the emotions of others. Sette, Hipson, Zava, Baumgartner and Coplan (2018) also used the Children's Behavior Questionnaire–Short Form Inhibitory Control Subscale, to explore the interaction between inhibitory control, temperamental shyness, and social adjustment in school. Their study of 3 to 6-year-old pre-schoolers found inhibitory control to be positively associated with sympathy and regulated school behaviours. Children with higher inhibitory control were more aware of their peers' feelings and more likely to behave appropriately in the classroom. Nakamichi (2017) found similar results in a study of 5 and 6-year-old public preschool students in Shizuoka, Japan. A Black/White and a Shine/Rain task were used to measure inhibitory control and Nakamichi (2017) found children with high inhibitory control to be more popular with peers and to have closer peer relationships than children with lower inhibitory control. Sette *et al.* (2018) added the factor of shyness to their study and observed that when shyness and higher inhibitory control were combined students showed lower levels of prosocial behaviour and popularity. They found having high inhibitory control and being shy limited the number of interactions that could lead to building relationships. The combination of shyness and strong inhibitory control negatively impacted social adjustment in preschoolers.

Researchers measuring the relationships between inhibitory control and social-emotional learning found different behaviour tasks to be more significantly correlated with specific elements of social-emotional learning. Di Norcia *et al.* (2015) explored the relationship between inhibitory control and social competence in 2 and 3-year-old Italian students. They analysed the differences between Clean-up and Musical Box, considered hot inhibitory control tasks, and Reverse Categorization,

Slowing Down Motor Activity and Lowering Voice that are cool tasks. Their study showed hot inhibitory control tasks were more associated with socio-emotional competence than cool tasks and found that inhibitory control was important for social skills development and protected against students displaying externalising problems. This finding supports the idea that hot inhibitory control is associated with emotion, affect and external motivators (Zelazo & Müller, 2002). Rhoades *et al.* (2009) found that the relationship between social-emotional competence and inhibitory control differed depending on the type of measurement tasks. They explored the role of inhibitory control in predicting social-emotional competence in 4 to 5-year-old children of varying ethnicities in the USA. Inhibitory control was measured using the Day/Night and Peg Tapping tasks. High scores on the Peg Tapping task were found to be a better predictor of social-emotional competence than the Day/Night task. Since the Peg Tapping task involves inhibiting a motor response it may be more strongly related to children's behaviour in preschool and signify their ability to slow down and consider the feelings of others. They found that hot inhibitory control tasks are positively correlated with social competence. Preschool children are at risk of reduced social-emotional competence when they have difficulties with inhibitory control skills (Rhoades *et al.*, 2009).

Researchers found inhibitory control and social-emotional learning to be positively correlated using both behaviour tasks and reported measures (Di Norcia *et al.*, 2015; LaBounty *et al.*, 2017; Nakamichi, 2017; Rhoades *et al.*, 2009; Sette *et al.*, 2018). Unlike studies on early mathematics and emergent literacy, reported measures were used, although they may not be as precise a measurement as behaviour tasks. Social-emotional learning outcomes measured using parent and teacher reports (LaBounty *et al.*, 2017; Sette *et al.*, 2018) found similar results to studies using behaviour tasks (Nakamichi, 2017). When children performed poorly on inhibitory control tasks it predicted aggressive behaviour (Di Norcia *et al.*, 2015). Sette *et al.* (2018) found that children who were shy and had more inhibitory control could have difficulties with social adjustment. Much like the findings for early mathematics and emergent literacy the relationship with inhibitory control varied by the measure used. Although emergent literacy and social-emotional learning have been studied as different entities, both play an important role in the development of children's interpersonal communication skills (Tickell, 2011). None of the studies above indicated a causal relationship between inhibitory control and social-emotional competence, but researchers did find evidence of the positive relationship between hot inhibitory control and social-emotional learning (Di Norcia *et al.*, 2015; Rhoades *et al.*, 2009).

Discussion

This review paper explored the relationships between inhibitory control, mathematics, emergent literacy, and social-emotional learning in early childhood education. In this section, we discuss the main findings from the 15 studies reviewed in-depth, offer methodological insight into inhibitory control measures and discuss the scope of their research design. Additionally, we identify several knowledge gaps and highlight the possibilities for future research.

Our paper analysed a wide range of international studies on the role of inhibitory control in early childhood education and found unique insights in each of the three areas of focus. Studies measuring the relationship of inhibitory control with both early mathematics and emergent literacy skills pointed to a stronger correlation with early mathematical skills (Allan *et al.*, 2014). This could be due to the nature of the tasks used to measure inhibitory control as in mathematics children are required to follow a line of reasoning and multiple steps potentially requiring higher levels of inhibitory control (Blair & Razza, 2007). Research performed since Allan *et al.*'s (2014) meta-analysis yielded similar findings while also exploring more diverse population samples. Researchers have built upon their work by examining the reliability and validity of existing inhibitory control measures and focusing on new variables to explore in relation to inhibitory control. One notable finding was children with higher level maths skills, regardless of their language status, can improve their inhibitory control and learning behaviours by taking part in multiple opportunities to practise solving maths problems (Son *et al.*, 2019). The same correlations between mathematical skills and inhibitory control were observed in students with developmental delays as with their peers (Son, *et al.*, 2019). Jabłoński (2013) suggested a relationship between the developmental timelines of inhibitory control and stages of emergent literacy. These findings may be because the prefrontal cortex is still maturing, reconstructing, and consolidating during childhood and through adolescence (Arain *et al.*, 2013). De Franchis *et al.*'s (2017) findings contradicted other studies, concluding that the relationship between inhibitory control and Italian emergent literacy was not correlated, perhaps due to the structure of the Italian language compared with the other languages studied. Our choice to include a focus on social-emotional learning is an acknowledgement of current trends in early childhood education. Studies show that inhibitory control correlates with children's social-emotional learning such as their ability to effectively socialise with their peers and develop friendships (Nakamichi, 2017). Along with the more traditional maths and literacy, social-emotional intelligence prepares children for the transition between preschool and primary school (Graziano, Reavis, Keane, & Calkins, 2007).

The studies analysed in this paper utilised a range of inhibitory control measures and their findings reflect the benefits and limitations of the measurement tools they utilise. Behaviour tasks and teacher reports were found to be more reliable measurements of children's inhibitory control than parent reports (Allan *et al.*, 2014). Besides using behaviour tasks as inhibitory control measures researchers would benefit from including multiple measures, as DeFlorio *et al.* (2019) did in their study with fruitful results. Different inhibitory control measures are better suited to measure specific aspects of learning outcomes for early childhood education. Hot inhibitory control, involving emotion or external motivators, is often related to social-emotional learning and cool, having limited emotional and no external motivator, inhibitory control to academic skills, such as early mathematics and emergent literacy (Zelazo & Müller, 2002). DeFlorio *et al.* (2019) found initial mathematical skills measures predicted subsequent cool but not hot inhibitory control. Di Norcia *et al.* (2015) found hot inhibitory control tasks positively correlated with social competence and Rhoades *et al.* (2009) concluded that when children had difficulties with hot inhibitory control, they exhibited reduced social-emotional competence.

The different results found by hot and cool inhibitory control tasks provide a promising avenue for future research to explore how each of the tasks relates to specific classroom activities. Although there has been much discussion about the differences between hot and cool inhibitory control there is potential for them to be considered in tandem. A closer examination and alteration of the tasks currently used to measure inhibitory control skills is needed. The relationship between inhibitory control and classroom practices can be seen in the Waiting for Bow and Forbidden Toy task as both require children to inhibit a prepotent response and are related to waiting until the teacher has completed giving directions before starting an activity. Based on the correlational relationship between early childhood achievement and inhibitory control, lesson plans can be developed using inhibitory control tasks. Cool tasks, such as Lowering Voice, are representative of children behaving appropriately during class and could be used to develop social-emotional learning. The different areas of early childhood education can overlap and according to Tickell (2011), the listening and speaking aspects of emergent literacy play an important role in interpersonal communication and impact personal, social-emotional development in children. Based on De Franchis *et al.*'s (2017) findings, future research with other languages could explore possible differences and similarities in the relationship with inhibitory control and emergent literacy. Researchers could explore the interaction between emergent literacy and social-emotional learning in respect to inhibitory control. Researchers may determine the direction of correlation and possibly determine causality by including multiple measures of inhibitory control. The use of randomised control trials, such as by DeFlorio *et al.* (2019), could help create a useful collection of strategies and practices to promote inhibitory control. Even without causation, recent findings present enough evidence to suggest that educators would do well to focus on classroom activities that encourage students to practice inhibitory control while engaging in authentic tasks such as numeracy learning games, playful vocabulary building, and positive social role-playing.

It should be noted that our paper was limited to analysing research published in the English language and leans towards representing Western, educated, industrialised, rich and democratic (WEIRD) populations (Henrich, Heine, & Norenzayan, 2010). For example, many of the relevant published studies on early mathematics were conducted in the USA. Future research by multilingual scholars of similar studies in different geographic locations, may yield more inclusive findings, better represent a variety of other populations and contribute to a wider cultural and global view of the topic.

Conclusion

All children deserve quality traditional academic and social-emotional education in early childhood to prepare them for their future learning. Preschool is an important time for children to develop as individuals and their inhibitory control levels are related to their achievement (Bohlmann & Dowdner, 2016). Identifying inhibitory control difficulties early on could help students' future learning outcomes (Rhoades *et al.*, 2009). In general, inhibitory control positively correlated with early mathematics, emergent literacy, and social-emotional learning measures (Allan *et al.*, 2014; DeFlorio *et al.*, 2019; Di Norcia *et al.*, 2015; Ekerim & Selcuk, 2018; Harvey

& Miller, 2017; Jabłoński, 2013; LaBounty *et al.*, 2017; McClelland *et al.*, 2014; Nakamichi, 2017; Ng *et al.*, 2015; Peredo *et al.*, 2015; Rhoades *et al.*, 2009; Sette *et al.*, 2018; Son, *et al.*, 2019). Inhibitory control could be considered an indicator of the potential for children's success given the strong correlations with the key early childhood education outcomes.

Educators, policymakers and researchers would benefit from knowing how to improve inhibitory control and enhance performance in early mathematics, emergent literacy and social-emotional learning. Inhibitory control could be a marker for success because of its strong correlation with achievement in early childhood education and should be considered as a starting point for researchers interested in exploring inhibitory control and academic achievement. Without evidence of causation, it is not known if high levels of inhibitory control lead to early achievement, vice versa or if both develop simultaneously.

More research is needed to establish whether inhibitory control is a prerequisite to success, a by-product of learning, or if it should be considered a goal of early childhood education in itself. How might hot and cool inhibitory control measures interact with one another? Can improved inhibitory control lead to higher achievement in all three areas? Research into the relationship between hot and cool inhibitory control and specific learning tasks could inform lesson planning and curriculum design. Further exploration of the relationship between specific classroom tasks and inhibitory control could provide useful insights for teachers, researchers and curriculum designers.

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Appendix

Table 1

Overview of the Studies Reviewed

<u>Study</u>	<u>Area(s) of Achievement</u>	<u>Inhibitory Control Measures</u>	<u>Hot or Cool</u>	<u>Country(s)</u>	<u>Ethnicity</u>	<u>Sample size</u>	<u>Age of Children in Years</u>
Bohlmann, N. L., & Downer, J. T. (2016)	Emergent Literacy	Pencil Tap	Cool	United States of America	48% Black or African American 31% Hispanic or Latino 12% White or Caucasian 3% Asian or Asian American 5% Multi-ethnic	603	3 - 4
De Franchis, V., Usai, M. C., Viterbori, P., & Traverso, L. (2017)	Emergent Literacy	Circle Drawing	Hot	Italy	Ethnicity breakdown was not reported	175	5
DeFlorio, L., Klein, A., Starkey, P., Swank, P. R., Taylor, H. B., Halliday, S. E., & Mulcahy, C. (2019)	Early Mathematics	Bear/Dragon Day/Night Gift Wrap Waiting for Bow	Cool Cool Hot Hot	United States of America	58.2% Hispanic/Latino 17.5% African American 13.7% multi-ethnic/other 5.5% Asian American/Pacific Islander 5.1% Caucasian	526	Time Point 1: 2 - 3 Time Point 2: 3 - 4 Time Point 3: 3 - 4
Di Norcia, A., Pecora, G., Bombi, A. S., Baumgartner, E., & Laghi, F. (2015)	Social-Emotional Learning [Social Competence]	Clean-up Lowering Voice Musical Box Reverse Categorization Slowing Down Motor Activity	Hot Cool Hot Cool Cool	Italy	Ethnicity breakdown was not reported	74	2 - 3
Ekerim, M., & Selcuk, B. (2018)	Emergent Literacy	Two-Part Peg Tapping	Cool	Turkey	Ethnicity breakdown was not reported	239	Time Point 1: 2 - 6 Time Point 2: 3 - 7

Harvey, H. A., & Miller, G. E. (2017)	Early Mathematics	Flanker Inhibitory Control and Attention Test	Cool	United States of America	67% Hispanic 16% Caucasian 12% African American 3% Mixed race 1% American Indian 1% Latvian	98	3 - 4
Jabłoński, S. (2013)	Emergent Literacy	Children Card Sort	Cool	Poland	Ethnicity breakdown was not reported	336	2 - 5
LaBounty, J., Bosse, L., Savicki, S., King, J., & Eisenstat, S. (2017)	Social-Emotional Learning [Social Cognition]	Children’s Behavior Questionnaire–Short Form Inhibitory Control Subscale	Not Specified	United States of America	82 % European-American descent 18% Bi-racial	34	3 - 4
McClelland, M. M., Cameron, C. E., Duncan, R., Bowles, R. P., Acock, A. C., Miao, A., & Pratt, M. E. (2014)	Early Mathematics	Day/Night Simon Says	Cool Cool	United States of America	61% White 18% Latino 13%. Multiracial 1% Middle Eastern 1% Other 0.5% African American	208	Timepoint 1: 3 - 5 Timepoint 2: 4 - 6
Nakamichi, K. (2017)	Social-Emotional Learning [Emotion Regulation]	Black/White Shine/Rain	Cool Cool	Japan	Ethnicity breakdown was not reported	66	5
Ng, F. F. Y., Tamis-LeMonda, C., Yoshikawa, H., & Sze, I. N. L. (2015)	Early Mathematics	Peg Tapping	Cool	United States of America	30.6% Chinese 24.3% Dominican 22.7% African American 22.4% Mexican	255	4
Peredo, T. N., Owen, M. T., Rojas, R., & Caughy, M. O. B. (2015)	Emergent Literacy	Forbidden Toy Snack Delay Wrapped Gift	Hot Hot Hot	United States of America	94% Hispanic 5% Hispanic and White 1% Hispanic and American Indian	100	Time Point 1: 2.5 Time Point 2: 3.5

Rhoades, B. L., Greenberg, M. T., & Domitrovich, C. E. (2009)	Social-Emotional Learning [Social-emotional competence]	Day/Night Peg Tapping	Cool Cool	United States of America	49.3% African American 38.4% Anglo-American 6.8% Hispanic 5.5% Multiracial or other	146	4 - 5
Sette, S., Hipson, W. E., Zava, F., Baumgartner, E., & Coplan, R. J. (2018)	Social-Emotional Learning [Social and School Adjustment]	Children’s Behavior Questionnaire–Short Form Inhibitory Control Subscale	Not Specified	Italy	79.5% Italian nationality	112	3 - 6
Son, S. H. C., Choi, J. Y., & Kwon, K. A. (2019)	Early Mathematics Emergent Literacy	Pencil Tap	Cool	United States of America	21.96% Caucasian 47.28% Hispanic 27.53% African American 7.12% Other races	939	3 - 4

Notes: Over 100 papers were initially reviewed and we narrowed them down based on the age group being preschool, focus on inhibitory control as a single construct and studies not included in Allan et al.’s (2014) meta-analysis. Some of the studies reported on multiple age groups, however, we focused on the parts related to preschool children.