Review article

Inhibitory control within the context of early life poverty and implications for outcomes

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ABSTRACT

Early life poverty confers risk for unfavorable outcomes including lower academic achievement, behavioral difficulties, and neurodevelopmental disorders. Disruptions in inhibitory control (IC) have been posed as one mechanism to explain the relationship between early life poverty and deleterious outcomes. There is robust research to suggest that early life poverty is associated with development of poorer IC. Further, poorer IC in children is related to decreased academic achievement and social competence, and increased externalizing and internalizing behavior. There is some parent-report evidence to suggest that IC is a mediator of the relationship between poverty and externalizing behaviors, as well as some limited evidence to suggest that IC is a mediator between poverty and academic achievement. Future work should aim to determine whether early life poverty's relation to IC could be explained by verbal ability which is thought to be central to the development of effective IC. In addition, future neuroimaging work should utilize IC fMRI tasks to identify key neural mechanisms that might contribute to a relationship between early life poverty and IC.

The United States Census Bureau has reported a general decline in the rate of poverty and an increase in median household income over the past five years (U.S. Census Bureau, 2019). While this report is encouraging, it is important to note that children continue to represent a disproportionate number of the nation's poor (Children's Defense Fund, 2017). In 2016, nearly 20% of the nation's children were living in poverty, a statistic notably higher than that of the overall national poverty rate of 12.7% (U.S. Census Bureau, 2017). Disproportionately high rates of poverty are particularly concerning in children, as research has consistently demonstrated that early life poverty is associated with a host of unfavorable short and long term outcomes such as lower academic/occupational achievement and increased risk for neurodevelopmental disorders, substance abuse, behavioral problems, and depression (Blair and Raver, 2012; Nusslock and Miller, 2016).

One potential mechanism that has been put forth to explain the relationship between early life poverty and these aforementioned negative outcomes is inhibitory control. Inhibitory control (IC) is a component of executive function (EF) which allows for the suppression of predominant, or prepotent, responses (Barkley, 2001; Best and Miller, 2010; Munakata et al., 2011). IC is one the earliest emerging higher order cognitive functions and an essential component of many other EF

processes, indicating its importance in child development (Best and Miller, 2010). Crucially, research has suggested that development of IC during early childhood may render it especially vulnerable to the external environment during this period. To date, the research literature centering on the development of IC within the context of early life poverty and related outcomes has not been reviewed. Therefore, the goal of this review is to determine whether the existing literature is consistent with the idea that disruptions in early childhood IC development may be one pathway by which early experiences of poverty contribute to greater risk for maladaptive outcomes. The current review will first present definitions of poverty and IC and indicate how each are commonly measured within the research literature. Then, studies will be presented which have examined normative developmental trajectories of IC. Next, an overview of research studies which have found associations between early life poverty and altered IC and an overview of studies which have found associations between altered IC and deleterious outcomes will be provided. This general overview of the associative literature will be presented in order to further provide evidence for IC as a potential mediator of early life poverty and functional outcomes. Finally, we will review all of the known research studies which have explicitly examined the relation between early life poverty, IC, and

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undesirable behavioral and academic outcomes, and more specifically have examined IC as a potential mediating mechanism between early life poverty and outcomes.

1. Defining poverty

Poverty within the context of this review refers to income poverty, which is broadly defined as "…the condition of not having enough income to meet basic needs for food, clothing, and shelter" (Brooks-Gunn and Duncan, 1997). Notably, the United States Census Bureau measures income poverty by comparing a household's income to a threshold which is three times the price of food intake for the year 1963 (U.S. Census Bureau, 2019). These thresholds are adjusted based on the number of household members. This Official Poverty Measure (OPM) does not account for the costs of clothing, shelter, utilities, or healthcare, nor does it adjust based on geographic location. For this reason, the OPM is considered to be a highly conservative measure of poverty in the research literature, one that likely does not fully capture the population of households that struggle to meet basic needs. The United States Census Bureau also provides a supplemental poverty measure which additionally takes cost for shelter, clothing, and utilities into account, and varies by geographic region (U.S. Census Bureau, 2019).

Many research studies have also used more encompassing measures of income poverty, such as relative income poverty – which uses half of the regional median household income for a threshold – and cutoffs at 200% of the OPM thresholds (Burchinal et al., 2008; Zheng, 2001). Other researchers use an income-to-needs ratio, which is calculated by dividing the household's total income by the number of household members. Neighborhood poverty, which is measured by the proportion of individual families living in poverty within a specific census tract, has also been increasingly used in the literature (Kim et al., 2019; Morrissey and Vinopal, 2018). Additional subjective measures have also begun to be used to more comprehensively capture whether income is sufficient to meet household needs and have been found to be strongly correlated with more objective measures (Castilla, 2010; Sacks et al., 2010). However, more objective measures using household income, neighborhood poverty, parental education, and poverty thresholds are much more widely used in the literature, and therefore are the focus of the current review.

2. Defining Inhibitory Control (IC)

IC is a component of EF that allows for the suppression of prepotent, or automatic, responses. It is important for effective goal-directed thoughts and behaviors, future planning, decision-making, and healthy social interactions. IC is considered to be one of the earliest emerging higher order cognitive functions and is an essential component of many other EF processes (Barkley, 2001; Best and Miller, 2010; Munakata et al., 2011).

IC processes are supported by various brain regions, including the dorsal lateral prefrontal cortex (dlPFC), ventral lateral prefrontal cortex (vlPFC), motor cortex, and dorsal anterior cingulate cortex (dACC) (Durston et al., 2002; Garavan et al., 2006; Hwang et al., 2010; Luria, 1973; Milner, 1963; Miyake et al., 2000; Goldstein et al., 2007; Whittle et al., 2020). The motor cortex is primarily tasked with ensuring the appropriate coordination of motor responses, the dACC is primarily implicated in error detection and conflict monitoring (or interference detection), and the vlPFC and dlPFC are tasked with executively orchestrating the appropriate responses (Ordaz et al., 2013). Working together, these regions allow for the successful inhibition of prepotent behaviors. Research has also suggested that the right hemisphere of the brain is more heavily implicated in IC processes (Chevrier et al., 2007; Garavan, Ross, and Stein, 1999).

Several researchers have delineated between "hot" and "cool" variations of IC (Allan et al., 2014; Huijbregts et al., 2008). "Hot" IC refers to IC processes that must be employed within the context of a task that is emotionally salient, while "cool" IC is strongly associated with more abstract tasks (Allan et al., 2014). For example, a hot IC task might be a response inhibition paradigm which includes the actual receipt of a desired reward, like money or food. Such hedonic reward allows for potentially increased ecological validity, but may make it more difficult to examine core underlying processes. The line between the two types can be blurry, especially in young children, and it is not yet agreed upon whether the distinction reflects two wholly separate processes or a broader pattern of automatic response suppression with increased complexity when emotional salience is included (Huijbregts et al., 2008). The majority of the studies reviewed examined "cool" IC in young children, however there are some studies which examine "hot" IC, primarily delay of gratification paradigm tasks.

3. Inhibitory Control (IC) assessment methods

The IC construct is indexed using many diverse methods. The two primary modalities are parent/teacher report and behavioral measures. Here we review the most commonly used measures in each of these modes of assessment, with a brief discussion of their strengths and limitations. The current review did not find widely used self-report measures of IC in young children. This likely reflects the difficulty/inappropriateness of using self-report to measure IC during young childhood.

3.1. Parent/teacher reports

IC in children is often assessed using methods that involve the report of a parent/primary caregiver or teacher. Individuals that spend a notable amount of time with the child in question can often provide helpful insights into behavior, thus offering a comprehensive measure of IC for that child, particularly when combined with behavioral measures. The measures discussed were the most commonly used across the reviewed literature.

3.1.1. Behavior rating inventory of executive function parent/teacher report (BRIEF & BRIEF-P)

The BRIEF is a broad measure of attention and general executive function assessment that was developed by child neuropsychologists for parents and teachers of school-aged children (Gioia et al., 2000, 2002). It traditionally consists of eight clinical scales: Inhibit, Shift, Emotional Control, Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor. Notably, the exact factor structure of the BRIEF has not been agreed upon within the literature. Initial exploratory factor analyses (EFA) suggested that the BRIEF consists of two factors/indices: the Behavioral Regulation Index (Inhibit, Shift, and Emotional Control scales) and the Metacognition Index (Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor scales) (Gioia et al., 2000; Halvorsen et al., 2019). The third index is a Global Executive Composite which consists of a combination of the Behavioral Regulation and Metacognition indices. Notably, more recent confirmatory factor analyses (CFA) have suggested a three-factor model consisting of nine scales (splitting the Monitor scale into Task Monitor and Self Monitor) which delineates between general behavioral regulation and more specific emotion regulation (Gioia et al., 2002; Egeland and Fallmyr, 2010; Roth et al., 2013). This distinction is relevant when studying IC, particularly when considering brain processes, as several researchers have hypothesized that tasks that involve increased emotional salience recruit different regions when compared to tasks that involve more basic inhibitory cognition (Castellanos et al., 2006). Despite the potential added utility of this distinction, the majority of studies that have used the BRIEF adhere to the traditional two-factor, eight scale version. IC in this version of the BRIEF is considered to be primarily captured by the Inhibit and Shift scales which compose the Behavioral Regulation Index (Gioia et al., 2002).

The BRIEF-P is a version of the BRIEF that was developed for

preschool children aged two years to five years 11 months (Gioia et al., 2003; Sherman and Brooks, 2010). The BRIEF-P includes several of the clinical scales that are included in the BRIEF: Inhibit, Shift, Emotional Control, Working Memory, and Plan/Organize. The clinical scales are grouped into three indices: Inhibitory Self-Control Index (ISCI), Emergent Metacognition Index (EMI), and Flexibility Index (FI). Finally, similarly to the BRIEF, the Global Executive Composite makes up a fourth index.

In studies which involve clinical samples, elevations on the BRIEF scales were found to be robustly associated with several diagnoses commonly characterized by difficulties with IC. Children with severe traumatic brain injury (TBI) were found to have significantly higher scores on the Global Executive Composite index when compared to children with orthopedic injuries (Mangeot et al., 2002). In another study, severe childhood TBI was also associated with higher scores on the Metacognition Index (Byerley and Donders, 2013). The BRIEF is most commonly used to identify youth who may have Attention-Deficit/Hyperactivity Disorder (ADHD), and children with ADHD have demonstrated higher scores across all of the BRIEF indices (Mahone et al., 2002; Toplak et al., 2008). More specifically, the Inhibit scale has shown utility in discriminating between children with ADHD Combined type and children with ADHD Inattentive type (Gioia et al., 2000; McCandless and Laughlin, L., 2007).

It is important to note that the BRIEF questionnaires are most often used in more clinically based studies which are focused on characterizing samples that may meet criteria for neurodevelopmental disorders, traumatic brain injury, and other disorders/conditions that are associated with notable executive function deficits. They are not as often used to characterize executive function deficits in normative samples within the research literature. In addition, items indexing IC on the BRIEF are rarely evaluated independently in the literature, and are most likely to be evaluated as a component of the Behavioral Regulation Index. For this reason, it should be acknowledged that studies that use the Behavioral Regulation Index as a measure of IC may be tapping broader constructs that encompass general self-regulatory processes.

3.1.2. Child Behavior Questionnaire (CBQ)

The CBQ is a parent-report questionnaire that assesses temperament in early to middle childhood (Rothbart et al., 2001). The questionnaire lists statements describing reactions to different situations and parents are instructed to indicate how much the reaction statement describes their child on a scale from 1 ("extremely untrue of your child") to 7 ("extremely true of your child"). Versions of the CBQ include the Standard Form (195 items), the Short Form (94 items), and the Very Short Form (36 items) (Rothbart et al., 2001). The Short Form was the most widely used version in the reviewed literature. The Standard and Short Forms are comprised of 15 scales each aiming to index different facets of behavior. The 'Inhibitory Control' scale is analogous to the definition of IC for this review, and consists of six items. The scale was developed to reflect the Rothbart's reactive and self-regulative model of temperament (Rothbart, 1989).

EFA of the Standard Form CBQ consistently revealed a solution with three factors. These three factors were determined to reflect Extraversion/Surgency, Negative Affectivity, and Effortful Control (Rothbart et al., 2001). CFA results were consistent with previous EFA solutions (Rothbart et al., 2001). Internal consistency of the Inhibitory Control scale was determined to be good for the assessed age groups (Rothbart et al., 2001). On the Short Form version of the CBQ, internal consistency for the Inhibitory Control scale was still determined to be good amongst middle to higher income White samples (Putnam and Rothbart, 2006). However, Putnam and Rothbart (2006) cautioned against using the Short Form in predominately lower income and/or African American samples, as there was a notable reduction in internal consistency. Instead, Putnam and Rothbart (2006) recommend using the full scales for the temperament dimensions of interest.

3.1.3. Limitations of parent/teacher report measures

While parent/teacher report questionnaires can be useful in providing ecologically valid measures of child behavior, there are several limitations. One limitation is the potential for "halo effects" or "devil effects" wherein parents/teachers may have a negative or positive feeling about an aspect of the child's behavior which could lead to global poor/favorable ratings as opposed to differentiation between domains of problematic versus unproblematic behaviors. An additional limitation is the potential for parental psychopathology to influence ratings of the child. For example, parents with increased depressive symptomology may be more likely to perceive more negative patterns of child behavior. Also, as discussed above, certain questionnaires may not be as appropriate for lower income or ethnically diverse samples. Rothbart et al. (2006) recommended that the CBQ short form not be used with lower income or ethnically diverse samples due to issues with content validity. These limitations should be taken into consideration when selecting parent/teacher-report measures for use in research studies.

3.2. Behavioral measures

Behavioral measures are important research tools that are used to observe/evaluate the behavior(s) of interest in a setting that is typically more controlled. Behavioral measures usually require that trained examiners/researchers administer them, allowing for assessment of behaviors in real time.

3.2.1. Stop Signal Task (SST)

The SST measures the ability to inhibit prepotent motor responses (Littman andTakács, 2017; Montgomery and Koeltzow, 2010). There are many variations of the SST, but typically it is a computerized task wherein the individual views arrows pointing either left or right. When individuals are presented with a left arrow they are instructed to press the left button, and when they are presented with a right arrow they are instructed to press the right button. For a proportionally smaller (typically approximately one-to-four ratio) number of the trials, a "stop signal" (e.g. a crosshair or an audio tone) is presented after the left/right arrow. When this stop signal is presented, the individuals are instructed not to press the left or right buttons thus inhibiting the prepotent motor response. The SST allows for the estimation of response inhibition latency, which distinguishes it from many other IC behavioral tasks (Verbruggen et al., 2019). This estimation, or stop signal reaction time (SSRT), is obtained by using a variable stop signal delay (SSD), or delay between presentation of the "go" arrow stimulus and the "stop" stimulus (Verbruggen et al., 2019). The SST was developed based on a race model, wherein researchers theorized that simultaneous "stop" and "go" processes are "racing" against one another (Logan et al., 1984). If the "stop" process is completed after the "go" process, then the prepotent response has not been effectively inhibited. This can either be due to the "stop" process being initiated too late, being too slow, or not being initiated at all (Logan et al., 1984).

The SSRT has been found to be associated with several psychiatric/developmental disorders that are generally characterized by difficulties with IC. A meta-analysis, which examined effect sizes of the relationship between SSRT and psychiatric/developmental disorders, found moderate effect sizes for the relationships between SSRT and ADHD, Obsessive-Compulsive Disorder (OCD), and schizophrenia (Lipszyc and Schachar, 2010). It is also important to note that the SST has commonly been used in neuroimaging studies and is associated with activation in the right inferior frontal gyrus (rIFG), a structure which has been repeatedly implicated in IC processes (Aron et al., 2003; Chevrier et al., 2007). Performance on the SST has been found to be significantly influenced by age, with younger individuals demonstrating greater difficulty inhibiting responses and having slower SSRTs than older individuals (Carver et al., 2001). This effect persisted even when younger participants were given more "child-friendly" versions of the SST, suggesting that this difference in performance is reflective of an immature

IC system, as opposed to difficulty understanding task instructions (Carver et al., 2001).

3.2.2. Go/No-Go Task (GNG)

The GNG is another behavioral task that is used to measure response inhibition. In this computerized task, the individual is presented with trials of "go" stimuli, wherein they are instructed to press a button, and "no-go" stimuli, wherein they are instructed to not press the button (Donders, 1969). The "go" stimuli trials make up a greater proportion of the presented trials – typically a four-to-one ratio – and this creates a prepotent "go" response. In GNG tasks, increasing errors of commission (pressing the button during a "no-go" trial) are indicative of greater difficulties with IC.

The GNG was found to differentiate between children with impulsivity/hyperactivity and children with inattention (Wright et al., 2014). Children with impulsivity/hyperactivity tended to make more errors of commission, while children with inattention made more omission errors (not pressing the button during a "go" trial) (Bezdjian et al., 2009). GNG tasks are frequently used with a large range of participants in the research literature, including younger children, perhaps due to their overall simplicity and flexibility of design. Age effects are still observed within the GNG paradigm, with younger individuals making more errors of commission than older individuals (Carver et al., 2001).

3.2.3. Stroop Task paradigms: Color-Word Test (SCWT), day-night task, finger tapping task

The Stroop task paradigms encompass a broad set of IC tasks that are designed to elicit the Stroop effect: the increased difficulty – evidenced by longer delay – associated with responding to task incongruent versus task congruent stimuli (Stroop, 1935). All Stroop tasks are described as measures of response inhibition, or the ability to not engage in the dominant response and to engage in a different response instead (Homack and Riccio, 2004).

The SCWT is broadly used, and the reviewed literature utilizes different variations. Fundamentally, the task entails the participant viewing different color words that are displayed in colored ink that varies from the color word name (Scarpina and Tagini, 2017). The individual is instructed to say the name of the color that the word is printed in, rather than the color word name. Reading the color words is the congruent – or prepotent – behavior, thus IC must be recruited in order to say the color of the words instead. It is crucial for the individual to be literate in order for word-reading to be the automatic behavior. For this reason, the SCWT is not appropriate for use in younger children, or individuals who do not know how to read. Fortunately, there are several non-verbal/no-reading-required versions of the task that can be used to illicit the Stroop effect.

The Day-Night task is a commonly used Stroop paradigm that is appropriate for use in younger children (Diamond and Taylor, 1996). The task involves the experimenter presenting the child with cards that have images of a sun or a moon on them. When children are shown the sun, they are instructed to say "night" and when they are shown the moon, they are instructed to say, "day". This task involves inhibiting the automatic response, which is to say, "day" to the sun cards, and "night" to the moon cards (Diamond and Taylor, 1996; Lengua et al., 2007). A non-verbal version of the Day-Night Stroop task is the Grass-Snow task, wherein the child is instructed to point to a green card when the experimenter says "Snow" and point to a white card when the experimenter says "Grass" (Lengua et al., 2007). Another commonly used non-verbal task is the Luria's Finger Tapping Task, in which the child is instructed to tap once with their finger when the experimenter taps twice and to tap twice when the experimenter taps once (Diamond and Taylor, 1996). Other variations of these Stroop tasks include the Bear-Dragon, and Butterfly (Lengua et al., 2007). Importantly, these tasks are designed for use in young children typically between the ages of three and five. Beyond early childhood, researchers have indicated that the tasks are too simplistic, and thus are likely not valid indices of IC

(Best and Miller, 2010; Carver et al., 2001).

The SCWT has been found to differentiate between children with ADHD and children with disruptive behavior who were not diagnosed with ADHD, wherein ADHD children demonstrated significantly increased interference on the task (Lavoie and Charlebois, 1994). Another study found that individuals with ADHD, Conduct Disorder (CD), and other emotional disorders demonstrated notable interference on the SCWT, and these groups were not significantly different from one another (Macleod and Prior, 1996). It is likely that IC function is affected in all of these disorders. The SCWT has also been found to differentiate individuals with frontal lobe lesions from healthy controls (Milner, 1963; Stuss et al., 2001). Similarly, the Day-Night Stroop and Finger Tapping tasks have been used to identify improvements in individuals with ADHD and related difficulties with inattention. (Dowsett and Livesey, 2000).

3.2.4. Flanker task

Similarly to the SCWT, the Flanker task measures interference control, or the ability to not engage in a dominant response. Unlike the SCWT, and more similar to the Day-Night Stroop-type tasks, the Flanker task is not reliant upon reading ability, and thus is appropriate for use in younger children. In the Flanker task, subjects view a target stimulus (e. g., arrow) that is flanked by non-target stimuli. The individual is told to press a button that matches the target stimulus. Sometimes the flanking stimuli will match the target stimulus, and sometimes they will not. The individual must suppress the prepotent response to match the flanking stimuli when there is a mismatch (Eriksen and Schultz, 1979).

Children with ADHD have been found to demonstrate greater RT congruency effects on the Flanker task than healthy controls (Crone et al., 2003; Konrad et al., 2006; Tsal et al., 2005). They were also less accurate and demonstrated lower efficiency than healthy controls (Mullane et al., 2009). There is some indication that the Flanker task is actually predominately measuring attention/inattention. However, it can be posited that the Flanker task is more broadly indexing conflict monitoring and ability to suppress a dominant response in order to match flanking arrows. It could also be argued that attention and IC processes are not mutually exclusive and the ability to recruit them may stem from the same broad cognitive process.

3.2.5. Delay-of-gratification/delay-discounting paradigms (DOG/DD)

DOG/DD paradigms encompass a broad category of behavioral tasks that are theorized to index IC. The task is based on the underlying concept that the longer the delay between the present moment and the future reward, the stronger the preference for a more immediate reward (Green et al., 1994). This preference can persist even when the future reward is greater than the more immediate reward. A preference for larger, more delayed rewards is thought to index greater self-control and IC, while a preference for smaller, more immediate rewards is thought to indicate greater impulsivity and lower inhibition (Green et al., 1994). Performance on DOG/DD tasks has demonstrated significant improvement at four years of age in comparison to children at three years of age, and continued improvement has been observed into adolescence (Green et al., 1994).

The classic DOG task in children is Mischel's (1974) "Marshmallow Test". Child participants were presented with a marshmallow or similar treat and instructed not to eat it. The examiner informed the child that they would receive an additional reward if they did not consume the treat while the examiner was away. Successful delay of consumption in preschool was associated with greater academic achievement and higher parent-rated self-control and coping skills in adolescence (Shoda et al., 1990). In recent years, the Marshmallow Test has been replicated in more diverse samples. In these recent studies, increased delay of consumption was not consistently related to higher parent-rated self-control and coping in later years, and the strength of the relation to academic achievement was notably reduced after controlling for ethnicity, home environment, and baseline cognitive ability (Watts et al., 2018).

Some researchers have suggested that DOG/DD paradigms may not be valid measures of IC in individuals who have experienced environmental deprivation or socioeconomic insecurity (Epstein et al., 2014). The reasoning behind this is that individuals from more chaotic environments might view the future as uncertain, and so increased delays to rewards suggest that reward receipt is increasingly unlikely (Epstein et al., 2014). As such, the choice to take the more immediate reward can be seen as adaptive and appropriate in contexts in which the future is uncertain. Implications and conclusions drawn from research studies utilizing DOG/DD paradigms in these populations should be made while keeping this in mind.

3.2.6. Limitations of behavioral measures

Behavioral measures are particularly useful for obtaining more controlled, objective measures of IC. However, there is always a concern that these kinds of measures have low ecological validity, that is, they may not be accurately capturing how IC functions in daily life. While many studies have revealed that IC behavioral tasks are related to functional outcomes, other studies have found that they are not related, while parent/teacher-report measures of IC were related to outcomes (Janssen et al., 2015). Altogether, this suggests that ideally multiple measurement modalities of IC should be used when it is the variable of interest.

4. Typical development of IC

Researchers have hypothesized that IC, or at the very least the foundation for IC, begins to develop soon after birth, as evidenced by experimental studies with infants that have used gaze and reaching tasks (Diamond, 1990; Holmboe et al., 2008, 2018). For example, seven-month-old infant participants demonstrated difficulty on tasks that required them to reach and grasp a particular toy when it was partially behind a barrier, characterized by a preference for reaching directly towards the toy rather than reaching past the barrier to obtain it (Diamond, 1990). Researchers further found that performance on this task increased with age (Diamond, 1990). Holmboe and colleagues (2018) have more recently found even earlier evidence for IC by demonstrating that better performance on a Freeze-Frame IC task at six months was related to improved IC and better general cognitive performance at nine months. Researchers have stated that performance on Freeze-Frame tasks is indicative of sustained attention, or the ability to maintain focus on a given stimulus despite the presence of other stimuli (Hendry et al., 2016; Holmboe et al., 2008). Additionally, researchers have suggested that sustained attention sets the foundation for IC as well as other important executive function processes (Hendry et al., 2006; Kochanska et al., 2000; Rothbart et al., 2001).

Maturation of IC is more easily observed in early childhood, particularly after language acquisition has occurred (Gagne and Saudino, 2016; Hughes and Ensor, 2007; Vallotton and Ayoub, 2011). Researchers have reported notable improvements in IC as early as 3½ years of age, or during the period of time when children are typically in preschool (Aksan and Kochanska, 2004; Diamond and Taylor, 1996; Kochanska et al., 2000). Diamond and Taylor (1996) found that children younger than 3½ years-old were unable to complete a Finger Tapping task, either due to frustration and/or task fatigue. Children aged 3½ years were able to complete the task despite exhibiting poorer performance than older children (Diamond and Taylor, 1999). Other studies corroborated these findings, demonstrating that three-year-old children reported understanding of task instructions but were consistently unable to inhibit responses to prepotent stimuli (Bell and Livesey, 1985; Livesey and Morgan, 1991). Thus, these results are likely reflective of relatively immature IC processes in three-year-old children, rather than misunderstanding of task instructions. Carlson (2005) found that performance on a DOG task improved significantly between two and four years of age. Overall, the research suggests that children may achieve an IC milestone at approximately 3½ years old wherein they are able to both verbalize

understanding of IC tasks and better inhibit prepotent responses.

IC continues to mature rapidly between the ages of 3½ years to six years. In particular, there are consistent differences in IC observed between individuals six years and older and individuals younger than six years. Performance on the Day-Night Stroop task was strongly associated with age, wherein children younger than six years exhibited significantly more interference errors and greater response latencies than children six years and older (Gerstadt, Hong, and Diamond, 1994). It is important to note that participants younger than six did not demonstrate this response latency or interference when completing a control condition of the task, indicating that differences in performance were not due to an inability to understand or remember multiple task instructions (Gerstadt, Hong, and Diamond, 1994). Similarly, age was significantly related to performance on a Finger Tapping task, in which younger children demonstrated more interference errors than older children (Diamond and Taylor, 1999). Notably, performance improvements on more complex IC tasks which may rely more heavily on working memory are observed during this period (Carlson, 2005; Garon et al., 2008) On Mischel and Mischel's (1983) classic Marshmallow Test, performance in children under five was significantly worse when compared with performance in children five to six years of age.

Zelazo and Frye's (1998) Cognitive Complexity and Control theory suggests that improvements in executive processes like IC can be explained by increased complexity and capacity for rule systems, which is characterized by greater self-reflection and improved metacognition. Based on this theory, the reason that older children gain the ability to actually follow IC task instructions is due to increased internal reasoning processes. Additionally, according to this theory, increased errors on IC tasks are suggestive of an inability to incorporate simultaneous rule systems in a stable way, which is consistent with the common types of errors observed in these tasks (e.g., perseverative, set loss, interference) (Zelazo and Frye, 1998). One hypothesis is that language acquisition and subsequent mastery facilitates increased capacity for internal reasoning and enables improved performance on IC tasks. Several studies have demonstrated that verbal ability is strongly related to IC performance, and one study has even set a temporal precedence, where increases in reading ability during preschool through kindergarten preceded additional gains in IC (Son et al., 2019).

Prior research suggests that changes and/or maturation in IC after the ages of seven to nine years-old is more subtle, and thus, more difficult to empirically detect (Casey et al., 1997; Christ et al., 2001; Fisher et al., 1997; Johnstone et al., 2007; Munoz et al., 1998). The research literature suggests that computerized IC tasks are best for measuring these small differences in response time and accuracy (Best and Miller, 2010). One study created a modified GNG task in which they were able to index partial errors of commission (Cragg and Nation, 2008). On this task, they demonstrated that children aged five to seven made significantly more partial commission errors than children aged nine to eleven (Best and Miller, 2010; Cragg and Nation, 2008). On an SST task, Johnstone et al. (2007), found that children improved response execution, but not response inhibition, across the ages of seven to twelve years-old, potentially reflecting improvements with processing and reaction time. Huizinga et al. (2006) reported improvement in performance on the Flanker task and the SST up until age eleven, after which performance was indistinguishable from that of fifteen – twenty-one year-olds. On the other hand, they observed improvements in performance on a Stroop task until the age of twenty-one years-old (Huizinga et al., 2006). It is unclear whether or not these small differences from late childhood to young adulthood represent meaningful effects on IC function in day-to-day life (Chevalier et al., 2014). Importantly, Petersen et al. (2016) found that IC is indexed best with different tasks at different timepoints during development, highlighting the challenges involved with measuring changes in IC over time. It is also important to note that IC tasks that incorporate other facets of executive function, like Working Memory or Shifting, are considered more complex and have the potential to demonstrate age-related improvements. Furthermore, researchers

should be aware of typical IC/EF developmental trajectories to ensure construct validity when measuring IC at different ages.

5. Poverty and IC development

Notable maturation of IC occurs during early childhood, suggesting that IC processes may be particularly sensitive to external stimuli/environments during this period. Several studies have demonstrated a strong relation between early life environments and IC (Allee-Herndon and Roberts, 2019; Chen et al., 2019; Evans and Kim, 2013; Finegood and Blair, 2017; Pacheco et al., 2018). However, few studies have examined poverty specifically. The following section will provide a review of studies that have linked early poverty to subsequent alterations in IC.

5.1. Poverty and self/parent/teacher report measures of IC

Researchers have found that moving into more impoverished neighborhoods from less impoverished neighborhoods was associated with a significant increase in teacher-reported dysregulated behavior in children, as measured by the BRIEF teacher report (Roy et al., 2014). The same researchers discovered that the opposite was also true: moving into less impoverished neighborhoods from more impoverished neighborhoods was associated with a significant increase in teacher-reported dysregulated behavior. Another study, which longitudinally examined the relation between family poverty and IC development, found that higher levels of poverty was associated with slower growth in IC on the CBQ between the ages of two and four years old (Moilanen et al., 2010). Further corroborating these findings, one recent study demonstrated a significant relation between greater early childhood poverty and subsequent lower scores on the BRIEF-SR Behavioral Regulation Index in adulthood (O'Neill et al., 2021) Although it is more difficult to hypothesize the nature of the relation between early poverty and IC in this case due to the retrospective (participants were assessed for childhood poverty in adulthood) nature of the study, it is notable that the association between early life poverty and IC continued to persist into adulthood in this study.

5.2. Poverty and behavioral measures of IC

A host of behavioral studies have examined the relation between poverty and IC. Lower income was associated with poorer performance on a DOG task similar to Mischel's Marshmallow Test in children (Evans and English, 2002). As poverty and other risk indices increased, the amount of time that children were able to delay gratification decreased.

Housing instability within the context of increased poverty has also consistently been found to be associated with lower IC behavioral performance in children (Raver et al., 2013; Roy et al., 2014; Schmitt et al., 2015). Increased years of experienced poverty and housing instability were each determined to be significant predictors of lower performance on a Flanker paradigm task among four year-old children (Raver et al., 2013). Similarly, greater poverty and housing instability were associated with worse performance on the Day-Night Stroop in a sample of preschool children (Schmitt et al., 2015). Relatedly, Roy et al. (2014) demonstrated that residential mobility across four waves spanning from early to middle childhood was associated with poorer performance on a Hearts-Flowers Stroop task in fifth-grade (final wave). The study sample was predominately composed of participants who fell below the national poverty line. Further, they found that this relation was moderated by higher poverty environments wherein children who remained in higher poverty performed significantly worse than individuals who moved from higher to lower poverty (Roy et al., 2014). These findings suggest that the experience of moving may only be significantly detrimental to IC within the context of poverty (e.g. moving from low to high poverty environments, or moving from one high poverty environment to another high poverty environment). Corroborating this, a recent study found

that greater years of poverty experienced from birth to nine years was associated with worse performance on a Flanker task in adulthood (Evans et al., 2021). Taken together, the results of these studies suggest that housing instability is a commonly experienced feature within the poverty context and may confer worse developmental outcomes than those that are suggested by financial hardship alone.

Relatively increased salivary cortisol and blunted diurnal salivary cortisol within the context of poverty has a demonstrated relation to decreased performance on IC behavioral tasks in children (Blair et al., 2011; Zalewski et al., 2012). In one study, three year-old children from lower income households exhibited greater interference on a Flanker-like IC task when compared to children from higher income households (Blair et al., 2011). This relation was partially explained by higher levels of salivary cortisol, suggesting a mechanism whereby increased stress from poverty affects IC task performance. Zalewski et al. (2012)conducted a similar study in which greater poverty was associated with worse performance on a battery of tasks indexing IC, and was additionally associated with less improvement, or change, in performance at a subsequent time point (Zalewski et al., 2012). When examining salivary cortisol, Zalewski et al. (2012) found that lower diurnal cortisol – or change in cortisol throughout the day – was associated with greater poverty.

Blunted cortisol release throughout the day is known to be reflective of a relatively blunted stress response system. Overall, the salivary cortisol literature is mixed which is likely reflective of variability in methodology of collection (Clements, 2013). However, there has been recent consensus that alterations from typical diurnal cortisol patterns are associated with several poor health and psychosocial outcomes (Metz et al., 2020; Miller et al., 2013; Newcomer et al., 1999). Prior studies have shown that blunted stress response within the context of chronic stress has negative impacts on memory and general cognition (Newcomer et al., 1999; Raffington et al., 2018) which suggests that IC development could be hindered. Further, the prefrontal cortex (which is the location of several brain regions implicated in IC) undergoes a protracted course of development in comparison to other brain regions, with full maturation not occurring until after adolescence (Giedd, 2004). Many researchers have theorized that this delayed maturation causes the prefrontal cortex to be particularly vulnerable to environmental influence (Casey et al., 2008). Chronic stress leading to chronic activation of the hypothalamic-pituitary adrenal (HPA) axis can damage glucocorticoid receptors in vulnerable areas like the prefrontal cortex (McEwen, 2003; McEwen and Morrison, 2013). This can result in desensitization of glucocorticoid receptors which can result in damage to surrounding tissues (McEwen and Morrison, 2013). Resource-scarce environments, such as those associated with poverty, may contribute to alterations in neural structures and could thus be contributing to deficits in IC function (Deater-Deckard et al., 2019; Hackman et al., 2010; Mueller et al., 2010; Noble et al., 2007; Noble et al., 2015a).

See Table 1 for an overview presented studies.

5.3. Summary of poverty and IC development

The highly replicated association between early life poverty and IC performance suggests that early lived environments are important in the development of IC. While several researchers have proposed potential pathways – such as housing instability, stress, and parental warmth – through which poverty could be related to IC, it is important to acknowledge that financial hardship may reciprocally exacerbate the influence of each of these pathways as variations in housing stability, stress, and parental relationship can occur independently of poverty. However, it may be both that poverty makes the occurrence of these factors more likely, and that their influences may be particularly deleterious within the poverty context.

Of note, the vast majority of the studies investigating associations between early poverty and IC used behavioral measures as IC indices, while only a few studies incorporated parent/teacher-report measures,

Table 1

Overview of presented studies examining relation between poverty and IC.

Author (s), Publication Date	Research Design	Poverty	IC	Research Findings
Blair et al. (2011)	Longitudinal; in home visits spanning from birth to 4 years.	Family Life Project; Oversampling of lower income families	Flanker Task	Lower income children had greater interreference errors on IC task.
Evans and English (2002)	Cross-sectional; two home visits wherein children completed RA-observed tasks and caregivers completed questionnaires.	Participants recruited from Head Start and public school districts; poverty defined as household income at/below federal poverty line.	DOG task	Lower income was associated with poorer performance on an IC task.
Evans et al. (2021)	Longitudinal; 4 timepoints spanning from middle childhood to adulthood	Half of the baseline sample was at or below federal poverty line.	Flanker task	Greater years of poverty from birth - 9 years associated with worse performance on IC tasks in adulthood
Deater-Deckard et al. (2019)	Cross-sectional; 1 visit wherein 14-year old participants completed an MRI/fMRI scan and caregivers completed questionnaires	Half of sample was "poor" or "near poor"	Multisource-interference task (MSIT) completed in scanner	Lower IC was associated with increased pubertal maturation among lower income youth.
Moilanen et al. (2010)	Longitudinal, 3 timepoints, spanning from 2 to 4 years old. Study sessions were conducted via in-home visits.	Parent-reported estimated household income	CBQ – Inhibitory Control subscale	Higher levels of poverty was associated with slower growth in IC between ages of 2 and 4 years old.
O'Neill et al. (2021)	Cross-sectional, Amazon MTurk adult sample	Reported on childhood poverty between 0 and 6 years, 6–12 years, and 12–18 years	CBQ – Inhibitory Control subscale	Greater early childhood poverty was associated with lower self-reported IC in adulthood.
Raver et al. (2013)	Longitudinal in-home visits spanning from birth to 4 years.	Income to needs ratio and duration spent in poverty was calculated. Participants recruited from Family Life Project, which was oversampled for poverty.	Flanker task	Increased years of poverty and housing instability associated with lower IC performance
Roy et al. (2014)	Longitudinal; 4 timepoints spanning preschool through 5th grade	Chicago Readiness Project; majority of the participants fell below federal poverty line	Hearts and Flower task; BRIEF Teacher Report	Residential mobility within context of poverty associated with poorer IC performance. Moving into more impoverished neighborhoods from less impoverished neighborhoods was associated with increased teacher-reported dysregulation.
Schmitt et al. (2015)	Longitudinal; 2 timepoints in fall and spring.	Participants were recruited from Head Start classrooms with average parent income	Day-Night Stroop	Greater housing instability was associated with worse IC performance.
Zalewski et al. (2012)	Longitudinal; 3 timepoints conducted in lab setting	Parent estimated total household income; approx. 18% of the sample fell below poverty line	Day-Night Stroop Bear-Dragon Stroop Grass-Snow Butterfly DOG task	Greater poverty was associated with worse performance on a battery of IC tasks

and even fewer solely utilized parent/teacher-report measures. As aforementioned, parent/teacher-report questionnaires can be particularly useful for indexing day-to-day functional deficits that may not necessarily be captured by behavioral measures. Future studies focusing on IC should ideally aim to include both behavioral and parent/teacher-reports.

6. Functional outcomes associated with IC deficits

As aforementioned, early life poverty has been robustly associated with IC deficits. IC is crucial for the optimal functioning of higher order executive processes like decision-making, goal-setting, and problem-solving. It is also essential in the maintenance of appropriate behaviors. Hence, research suggests that IC deficits are associated with several unfavorable functional outcomes perhaps reflecting increased difficulty recruiting these higher order processes. Reduced academic achievement and problem behaviors have been the functional outcomes most commonly linked with IC deficits.

6.1. Academic achievement

A meta-analysis indicated that across the literature, there was a modest positive effect size ($r = 0.27$) of IC's relation to academic achievement in preschool and kindergarten (Allan et al., 2014). This meta-analysis also revealed that generally, IC was more strongly related to math achievement than reading/literacy achievement, suggesting that IC is especially important for quantitative reasoning. However, the authors emphasized that the relationship between IC and reading

achievement was still significant, indicating the global utility of IC in academic proficiency and achievement (Allan et al., 2014).

A Stroop-like task, in which children had to choose a smaller amount of candy instead of a larger amount in order to receive the larger reward, was significantly related to verbal ability measured by the gold-standard Peabody Picture Vocabulary Test (PPVT-3), wherein worse performance on the task was related to lower PPVT-3 scores (Carlson et al., 2005). Another study demonstrated that poorer IC performance was related to lower acquisition of reading and math skills in preschool and kindergarten (Son et al., 2019). Further, this study modeled the data using cross-lagged path models and demonstrated a bidirectional effect, wherein reduced early math skills also predicted greater IC at later timepoints. This bidirectional relation of IC and math achievement is noteworthy and could represent a developmental mechanism whereby IC allows for acquisition of certain math skills, which then facilitate further IC maturation, and so on. This theory is beyond the scope of the current review, but would be a compelling topic for future research.

Another study found that poorer performance on a GNG task paradigm at the start of elementary school was linked to lower scores on the Performance Indicators in Primary School (PIPS), a test of reading and math proficiency, over the course of three years (Bull et al., 2008). This finding suggests that not only might IC be related to academic achievement proximally, but may continue to be related distally as well, emphasizing the importance of early IC development. Support for the idea of more distal academic impacts of IC was found in another study which demonstrated that both behavioral and teacher assessments of IC in preschool were associated with subsequent mathematic and reading performance in kindergarten, after controlling for fluid intelligence, age,

and IC measures in kindergarten (Blair and Razza, 2007).

There are several potential pathways that may explain the robust relation between IC and academic achievement. On the one hand, research indicates that the ability to inhibit prepotent responses is imperative in allowing individuals to maintain focus and attention in classroom settings, and thus allow for the learning of various academic concepts (Allan et al., 2014). In addition, the inability to inhibit prepotent responses could lead to uninhibited behaviors that may cause disruption to classroom environments or internal emotional processing and hinder learning. These unfavorable behaviors which have been linked to differences in IC are worthy of further exploration and discussion.

6.2. Behavior

6.2.1. Externalizing behavior

There are a plethora of studies that have found that lower levels of IC are associated with higher levels of externalizing behavior (Buss et al., 2014; Eisenberg et al., 2009; Schachar et al., 1993; Schoemaker et al., 2013). Externalizing behaviors are problematic behaviors that are generally characterized by disruption, aggression, and impulsivity (Liu, 2004). These behaviors are thought to be reflective of an inability to appropriately process thoughts and feelings, which results in them being expressed outwardly, or "externally" (Liu, 2004). Increased externalizing behaviors have been strongly implicated in increased risk for juvenile delinquency, substance abuse, and behavioral disorders like ADHD, Oppositional Defiant Disorder (ODD), and CD (Campbell, 2008).

Hughes and Ensor (2011) demonstrated that changes in performance on a latent construct of EF in four to six year-old children, which included IC measures, was predictive of less teacher-reported externalizing behavior problems at a subsequent timepoint. The researchers pointedly highlighted that change or "growth" on the executive function construct across timepoints was predictive of performance as opposed to performance at any individual timepoint (Hughes and Ensor, 2011). This finding makes sense after recognizing that significant development of EF broadly, and IC processes more specifically, is occurring in four to six year-old children. Another study utilized path analysis to demonstrate that performance on the Day-Night Stroop task in four year-old children was predictive of parent-reported externalizing behavior as measured by the Child Behavior Checklist (CBCL) at age six (Olson et al., 2011). Namely, poorer performance on the Day-Night Stroop task was predictive of higher parent-reported externalizing behaviors. Interestingly, the reciprocal relation was found not to be true: CBCL scores obtained prior to the collection of Day-Night Stroop task data were not predictive of task performance (Olson et al., 2011). This finding provides preliminary evidence for the unidirectional nature of the relation between IC and externalizing behaviors. Further supporting this, one research study found that IC at T2 (timepoint two), measured by Stroop, GNG, and DOG paradigms, mediated the relation between maternal-child interactions at T1 (timepoint one) and externalizing problems at T3 (timepoint three) (van Dijk et al., 2017).

In another study, researchers demonstrated that better IC, indexed by the Inhibitory Control subscale of the CBQ, was related to lower parent/teacher-reported externalizing behavior on the CBCL and Caregiver-Teacher Report Form (C-TRF), as well as better performance on a behavioral "Special Toy" sharing task which was meant to index aggressive behaviors (Utendale and Hastings, 2011). Further, they found that the relation between higher IC and fewer externalizing behaviors was moderated by age, wherein the relation between IC and externalizing behaviors was insignificant for pre-preschool children, significant for preschool-age children, and then significant with a more pronounced effect size for kindergarten-age children (Utendale and Hastings, 2011). This moderation finding is particularly notable, as it suggests that lower IC becomes increasingly indicative of externalizing behaviors with age. This could be reflective of IC deficits becoming more pronounced with age, whereby children with lower IC are unable to adapt as effectively to

the traditionally structured environments that are characteristic of formal learning.

6.2.2. Emotion regulation

Several studies have also indicated that lower IC is related to increased difficulties with emotion regulation, which has been shown to be imperative for healthy social-emotional functioning (Bartholomew et al., 2019; Rhoades et al., 2009; Tottenham et al., 2011). Poorer performance on a "Simon Says" IC game and DOG task was correlated with decreased performance on a behavioral emotion regulation task wherein three and four year-old children had to control their emotional expression in response to receiving a gift that they did not want (Carlson and Wang, 2007). Performance on this task was also associated with parent-reported IC, in which lower parent-reported IC was related to poorer performance on the emotion regulation tasks. A similar study conducted in a sample of five to eight year-old children supported these findings, demonstrating that better performance on a GNG task was associated with better control of emotional expressions during the disappointing gift paradigm after controlling for age and sex (Hudson and Jacques, 2014).

Although IC is typically implicated in externalizing behaviors, there is some emerging evidence that it is related to internalizing behaviors as well. In contrast to externalizing behaviors, internalizing behaviors are problematic patterns of behavior that are typically directed inwardly, or "internally" (Keiley, 2000). Some examples of internalizing behaviors include depressive thoughts, anxiety/worry, and rumination. Internalizing behaviors increase risk for depression, anxiety disorders, and suicide attempts, particularly during adolescence (Keiley, 2000). Rhoades et al. (2009) found that four to five year-old children who demonstrated poorer IC on a Day-Night Stroop task and Finger Tapping task exhibited more internalizing behaviors and poorer teacher-rated social skills. The researchers note that the ability to identify these behaviors and social skills difficulties earlier offer more time to enact an effective intervention and potentially prevent some of the insidious outcomes implicated with internalizing behaviors (Rhoades et al., 2009). See Table 2 for an overview of presented studies.

6.3. Summary of outcomes implicated in IC deficits

As evidenced, there are a range of deleterious outcomes robustly associated with IC that affect the quality of many facets of life for youth. Challenges in academic achievement and behavioral functioning (emotion regulation, internalizing/externalizing behaviors) early on confer increased risk for continued deficits in these areas through adolescence and into adulthood. This research highlights the importance of identifying populations most at risk for IC deficits to ensure that effective interventions are implemented as early as possible in order to mitigate poor outcomes.

7. Poverty, IC, and outcomes

The relation of increased early life poverty to decreased IC has support within the research literature (Allee-Herndon and Roberts, 2019; Chen et al., 2019; Evans and Kim, 2013; Pacheco et al., 2018). Similarly, as reviewed above, poverty has been implicated in many unfavorable outcomes including poorer executive function, blunted stress responses, and worse academic achievement (Allan et al., 2014; Eisenberg et al., 2009; Schachar et al., 1993; Schoemaker et al., 2013). Further, there is a well-researched relationship between early life poverty and alterations in several prefrontal brain regions which have been implicated in IC function. For example, reduced prefrontal gray matter volume, reduced prefrontal cortical surface area, and altered patterns of activity during functional magnetic imaging (fMRI) tasks are common findings (Durston et al., 2002; Hair et al., 2015; Mueller et al., 2010; Noble et al., 2015a). However, relatively few studies have explicitly examined IC as the mechanism explaining early poverty's – and correlates of early poverty's

Table 2
Overview of presented studies examining relation between IC deficits and outcomes.

Author (s), Publication Date	Research Design	IC	Outcomes	Research Findings
Blair and Razza (2007)	Longitudinal; children recruited from Head Start preschools	Peg tapping CBQ	Pre-CTOPPP PPVT-3	Worse IC performance associated with subsequent worse reading and math performance in kindergarten.
Bull et al. (2008)	Longitudinal; 3 timepoints, participants recruited from nursery school	Shape school	PIPS	Children who performed better on IC tasks in nursery school exhibited better performance on reading and math performance tests in primary school.
Buss et al. (2014)	Longitudinal; 2 timepoints (preschool and kindergarten)	DOG task	Berkeley Puppet Interview Health Behavior Questionnaire	Poorer performance on IC task was associated with increased externalizing behavior.
Carlson et al. (2005)	Cross-sectional; 3 and 4 year old healthy child participants	Less is More task	PPVT-3	Worse performance on IC task was related to lower scores on PPVT.
Carlson and Wang (2007)	Cross-sectional; 3 and 4 year-old preschool children	Simon Says DOG task	Disappointing Gift task	Lower IC performance was associated with worse performance on a behavioral emotion regulation task
Hudson and Jacques (2014)	Cross-sectional; 5–8 year-old children	GNG task	Disappointing Gift task	Better IC performance associated with improved behavioral emotion regulation
Hughes and Ensor (2011)	Longitudinal; 2 timepoints	Day-Night Stroop	Strengths and Difficulties Questionnaire	Changes in IC associated with less teacher-reported externalizing behavior
Olson et al. (2011)	Cross-sectional; preschool children in different countries	Day-Night Stroop Grass-Snow Stroop CBQ	CBCL	IC performance was associated with increased parent-reported externalizing behavior.
Rhoades et al. (2009)	Subset of preschool children from PATHS program	Day-Night Stroop Finger tapping task	Preschool and Kindergarten Behavior Scales	Better IC performance was associated with better teacher-rated social skills.
Utendale and Hastings (2011)	Cross-sectional; pre-preschool to kindergarten children	CBQ	CBCL	Relation between higher IC and fewer externalizing behaviors was

Table 2 (*continued*)

Author (s), Publication Date	Research Design	IC	Outcomes	Research Findings
				moderated by age: insignificant for pre-preschool children, significant for preschool children, and significant with pronounced effect for kindergarten children.
van Dijk et al. (2017)	Longitudinal; 3 timepoints; mother child dyads	Shape School Inhibit task Snack DOG task GNG task	C-TRF Attention Problems and Aggression scale	Relationship between mother-child interactions and hyperactivity/impulsivity was explained by IC performance

– relation to one or more of these outcomes.

7.1. Parent/teacher-report

Within the context of poverty, increased chaos in the home at age three was related to increased problem behavior at age five, as measured by the Eyeberg Child Behavior Inventory Intensity scale and the CBCL Externalizing scale (Hardaway et al., 2012). The researchers also examined whether IC, as measured by the Inhibitory Control scale of the CBQ at age four, explained any relation between home chaos and problem behavior. The researchers found that their proposed mediation model was a good fit, indicating that IC partially mediated the relation between home chaos and problem behaviors (Hardaway et al., 2012). More specifically, increased home chaos predicted worse subsequent IC which then partially explained higher instances of problem behavior at a later timepoint. The findings of this study are particularly noteworthy, as they suggest not only independent effects of home chaos within the context of poverty and IC to problematic outcomes, but they also test a mechanistic model which fits all facets (poverty, IC, and behavior) together.

7.2. Behavioral

Results of behavioral research that has examined IC as a mechanism explaining relations of poverty to outcomes have been mixed. Increased adversity within the context of poverty was associated with lower school readiness according to the Bracken Basic Concepts Scale, Third Edition, Receptive (BBC-3:R) (Brown et al., 2013). Further, evidence for a mediation was supported whereby performance on the Day-Night Stroop task in winter explained the relation between increased adversity in the fall and school readiness in the spring: Increased adversity was associated with lower IC, which partially mediated the relation to decreased school readiness (Brown et al., 2013). Another school readiness study found that an intervention targeting augmentation of child IC predicted improved subsequent school readiness in a sample of economically disadvantaged children in a Head Start preschool (Bierman et al., 2008) . Other researchers demonstrated that there was a significant relation between increased residential instability within the context of economic disadvantage and lower performance on the Day-Night Stroop task along with lower concurrent academic achievement. They also found that increased performance on the Day-Night Stroop task mediated the relation between residential instability and

academic achievement at the end of the school year (Bierman et al., 2008). In all, these studies suggest that IC is a potentially crucial mechanism of EF that enables children to perform well academically, and is also negatively implicated within the context of poverty.

However, these behavioral findings with IC are not as consistent when examining behavioral/social outcomes. One study demonstrated that higher cumulative risk measured at three years of age (with poverty included as one of nine risk indices) was associated with both poorer performance on a battery of IC tasks (DOG, Day-Night, Grass-Snow, Bear-Dragon, and Butterfly) and poorer social competence at a subsequent timepoint (Lengua et al., 2007). While cumulative risk, rather than poverty alone, was the independent variable of interest it is important to note that all other cumulative risk indices (e.g. single parent status, racial minority, number of household moves in child's lifetime) are highly correlated with increased poverty and thus, higher cumulative risk significantly increases likelihood of impoverished environment (Lengua et al., 2007). The researchers examined whether there was a mediating effect of IC performance on the relation between cumulative risk and social competence. Their results indicated that there was no significant mediating effect of IC performance. It is important to note that the subsequent timepoint occurred six months after the initial timepoint, and it was unclear whether or not the children were enrolled in preschool at either of the timepoints. Previous research has indicated that the relation between poverty and IC increases with age, and that poorer IC is especially indicative of poorer social/behavioral outcomes once children are enrolled in school or preschool (Diamond and Taylor, 1999; Gerstadt et al., 1994; Utendale and Hastings, 2011). The researchers acknowledged that ideally, it would be important to have additional timepoints for data collection (Lengua et al., 2007). In more specific terms, it would be especially informative to include a timepoint after the children have started preschool or elementary school.

Lewis et al. (2007) examined the relation between child placement instability and parent-reported Oppositional and Externalizing behaviors on the CBCL. Participants were five and six year-old children, who had previously been in foster care, and had either been placed in multiple foster care homes, or who had been adopted into a singular home. An additional participant group included children who were not adopted and had never been in foster care. The researchers were additionally interested in the potential mediating effects of IC, measured by the Day-Night Stroop task. Again, while placement instability is not an explicit measure of poverty per se, previous research has demonstrated that residential instability is a common feature of impoverished environments (Bierman et al., 2008). Therefore, the results of this research could provide insights into the development of IC and subsequent outcomes within the context of early life poverty. Surprisingly, while increased placement instability was independently related to poorer performance on the Day-Night Stroop task and increased Oppositional Behaviors on the CBCL, there was no evidence for a mediatory effect of IC performance (Lewis et al., 2007). The researchers suggested that this lack of observed mediation could be due to the outcome measure that was used, and suggested that a teacher-report version of the CBCL – the C-TRF – might better reflect the externalizing behaviors that are implicated in measured IC deficits. It is also worth noting that Lewis et al. (2007) ensured that all participant groups were approximately equal in terms of socioeconomic status (SES), and did not examine a moderating effect of household income, or include SES as a covariate. Lastly, placement instability within the context of the foster care system may confer an entirely different pattern of risk than that of financial adversity alone. See Table 3 for an overview of presented studies.

7.3. Summary of poverty, IC, and outcomes

In sum, there is some research which indicates that parent-report measures of IC explain the relation between early life poverty and externalizing behaviors. In addition, there have been a few behavioral studies which have suggested that IC explains the relation between early life poverty and academic achievement. However, behavioral studies do not provide support for IC as a mediator for early life poverty and social/emotional behaviors. It is possible that this conflicted literature is due in part to the paucity of research that has directly examined the interrelations of early life poverty, IC, and academic/behavioral outcomes. The findings in the literature suggesting potential relationships indicate the importance of additional research that more directly tests hypotheses about such mediating relationships.

Table 3
Overview of presented studies examining IC as a mediator of poverty and outcomes.

Author (s), Publication Date	Research Design	Poverty	IC	Outcomes	Research Findings
Bierman et al. (2008)	Intervention, classrooms assigned PATHS (targeting EF development) program or usual practice	Participants were recruited from the Head Start program	Day-Night Stroop	Expressive One-Word Picture Vocabulary Test; Social Competence Scale	Augmentation of IC through PATHS was related to increased school readiness.
Brown et al. (2013)	Longitudinal, 3 timepoints. Child assessments with RA over the school year during fall, winter, and spring	Participants recruited from Head Start program; family income to needs ratio computed for each participant	Day-Night Stroop Peg tapping task	Bracken Basic Concepts Scale Third Edition, Receptive (BBC-III)	Increased adversity associated with decreased school readiness; IC (Day/Night Stroop) mediated this relationship.
Hardaway et al. (2012)	Longitudinal, 3 timepoints. 3 h home visits wherein children completed RA-observed tasks and caregivers completed questionnaires.	Participants were recruited from SNAP WIC program in metropolitan areas across the U.S.	CBQ IC subscale (13 items)	Eyeberg Child Behavior Intensity Scale & CBCL Externalizing Scale	Increased home chaos within the context of poverty was associated with higher scores on Intensity and Externalizing Scales. IC mediated this relationship.
Lengua et al. (2007)	Short-term (6-month) longitudinal consisting of 2 timepoints. Mothers and children completed a battery of tasks and questionnaires.	Cumulative risk, with poverty and poverty covariates included as indices	Day-Night Stroop Bear-Dragon Stroop Grass-Snow Stroop DOG task Butterfly GNG task	Social Skills Rating Scale (SSRS)	Cumulative risk associated with IC and social competence, but not mediating effect of cumulative risk on social competence through IC was found.
Lewis et al. (2007)	Annual assessment which occurred in participant homes. Parents and children completed questionnaires separately.	Poverty covariate: placement instability	Day-Night Stroop	CBCL	Greater placement instability was related to higher oppositional behaviors and poorer IC performance, however no mediating effect of IC was found.

8. Summary, areas for literature expansion, and future directions

8.1. General summary

As one of the first emerging higher order functions, IC sets the stage for the development of future EF processes, further emphasizing its importance (Best and Miller, 2010). Children exhibit notable gains in IC during early preschool years, with continued improvement up until around age six. Smaller improvements in IC have been found after this age up until as late as early adulthood, although it in unclear whether these gains are also implicated in day-to-day functional improvements. Some emerging research has shown that early life poverty is related to poorer IC as indexed by both parent/teacher-report and behavioral measures, and that poorer IC is related to worse academic achievement and school readiness, as well as increased externalizing and internalizing behaviors, and worse emotion regulation and social competence.

Research investigating IC as a potential mediator of early life poverty to unfavorable outcomes was limited and mixed. There was some preliminary evidence to suggest that IC tasks explained the relation between early life poverty and academic achievement. There was also some limited evidence to suggest that parent-reported IC explained the relation between early poverty and externalizing behaviors. However, there was no evidence to date to suggest that IC, as measured by behavioral tasks, explained the relation between early poverty and social competence or externalizing behaviors. This is primarily due to the dearth of research in this area.

Brain regions that are commonly recruited in IC fMRI tasks are the vlPFC, dlPFC, dACC, and motor cortex. It has been hypothesized that chronic stress and resource deprivation within the context of early life poverty could lead to altered developmental start points and/or trajectories for IC by way of disruptions of environmentally vulnerable prefrontal structures. However, there is as of yet no research directly testing links between early poverty, prefrontal brain activation, and IC across developmental stages.

8.2. Future research directions

The mixed preliminary evidence suggests that additional targeted research is sorely needed to further the understanding of IC within the context of poverty, in order to develop effective points for intervention that will mitigate negative outcomes (Pietto et al., 2018). Research indicates that children living in poverty are especially vulnerable to IC deficits which are then linked to poor outcomes, and this increases the urgency of more comprehensively investigating these relationships. In addition, in order to foster development of interventions, it will be important to continue investigating common correlates of poverty that may be leading to IC deficits. Throughout the literature, the most commonly reviewed correlates of poverty were residential instability and verbal ability. These constructs should be further examined as mechanisms of early poverty's influence on IC development.

8.2.1. Need to incorporate multiple measures of IC in future studies

The majority of studies reviewed above included only one measure of IC, typically either parent report or a behavioral measure. Few studies included multiple types of measures, making it difficult to interpret different findings across studies and populations. As such, it will be critical in future research to include multiple methods of assessing IC to understand both the relative utility of different measures in predicting outcomes and relationships, as well as to better understand the unity or diversity of the construct of IC. Ideally studies would include both parent and teacher report for younger children, and self-report as children become able to validly report on their own behavior. Further, studies should also incorporate behavioral measures of IC, which would ideally include multiple behavioral measures in the same study to assess convergent validity, though we recognize the practical challenges of this

in terms of participant burden.

8.2.2. Residential instability

Residential instability has been reliably associated with IC development. In addition, increased residential instability is associated with increased poverty. However, residential instability can occur independent of poverty, and may or may not interact with poverty in predicting child outcomes. For example, it is important to note that outside of the poverty context, residential instability may not confer significantly worse IC (Roy et al., 2014). As such, when modeling predictors, outcomes, and covariates it will be important to include residential instability as a potential pathway between early poverty and IC development, as well as to examine whether it interacts with poverty to predict IC (e. g., residential instability more strongly associated with IC in the context of poverty).

8.2.3. Verbal ability

It will also be important to examine whether relationships between poverty and IC might be influenced by a relationship between poverty and other cognitive functions. For example, a potentially important factor that could help to explain poverty's influence on decreased IC performance is verbal ability. Children from more impoverished environments have consistently displayed decreased verbal ability in comparison to higher income peers, potentially reflecting more poorly resourced schools or decreased interaction with busy parents (Smith et al., 1997). Verbal ability's relationship with IC is well established within the literature, and notably many of the research studies presented in the current review included verbal ability as a covariate (Salmon et al., 2016). Son et al. (2019) found that increased reading ability, but not math ability predicted IC gains at a later timepoint. Zelazo and Frye's (1998) Cognitive Complexity and Control theory, which is based on Vygotsky's Sociocultural Theory, suggests that improvements in executive processes like IC may be explained by increased complexity and capacity for rule systems, which is characterized by greater self-reflection and improved metacognition. It has been proposed that increased self-reflection and improved metacognition, termed "internalization", is facilitated by the acquisition of language and subsequent self-talk (Salmon et al., 2016; Vygotsky and Luria, 1978). Lending more credence to this theory is the fact that relative gains in IC are observed after children typically learn to talk (Diamond and Taylor, 1996; Moriguchi et al., 2008). One study demonstrated that participant performance – especially the performance of younger children – on a variation of the SST was improved when they were instructed to label task stimuli and intended action (Kray et al., 2009). Winsler et al. (2000) observed that children with behavioral problems used increased irrelevant self-talk during problem-solving in comparison to controls. On the other hand, while IC and verbal ability are frequently shown to be correlated within the literature, it is entirely possible that these constructs are developing independently, or that there is an additional overarching construct which is driving maturation of both. Future research should aim to better specify the nature of the relationship between verbal ability and IC.

8.2.4. Poverty measures

Of important note, the majority of the studies discussed in the current review utilized categorical methods or discrete groups as opposed to measuring poverty on a continuous scale. Creating strict cutoffs (e.g. poverty vs. no poverty) can in some cases impose an artificial boundary wherein participants that did not make the cutoff are still experiencing notable financial disadvantage. For this reason, a mix of continuous and categorical measures of poverty both within and between studies should ideally be used.

8.2.5. Classroom intervention: tools of the mind

Tools of the Mind is an intervention program that was developed by Bodrova and Leong (2006) for the purpose of facilitating development of

self-regulatory functions (with an emphasis on IC) in early childhood. The program is based on Vygotsky's Sociocultural Theory of Development which highlights the importance of social learning and language in cognitive development (Vygotsky and Luria, 1978). For preschool-aged children, *Tools of the Mind* utilizes make-believe and pretend play to encourage usage of self-regulation strategies. For kindergarten-age children, the program focuses more on emphasizing development of self-regulation within the context of different academic subjects (e.g., Scaffolded Writing). In a randomized clinical control trial, Solomon et al. (2018) found that preschool-aged children who underwent the *Tools of the Mind* program, and who were rated by parents as having difficulties with attention, demonstrated improvements on an IC task when compared to children who completed a general pretend play curriculum. Another randomized control trial found that kindergarten children who took part in *Tools of the Mind* curriculum demonstrated improvements in reading and writing performance, as well as improvements in EF when compared to kindergarten children enrolled in workshops (Diamond et al., 2019). Barnett et al. (2008) found that a classroom which had implemented *Tools of the Mind* reported less behavior issues, explained by reductions in externalizing and internalizing behaviors, in comparison to a classroom which employed the typical curriculum. Notably, the children in this classroom came from less resourced backgrounds, suggesting that this curriculum could be beneficial for individuals regardless of socioeconomic status. Additional randomized clinical control trials should be conducted centering on individuals from impoverished backgrounds in order to determine whether this curriculum can be consistently and effectively implemented in lower resourced schools.

8.2.6. The importance of neuroimaging

To date, there are no known studies that have both neurally and behaviorally investigated IC development within the context of poverty in young children. As aforementioned, altered patterns of prefrontal activity during fMRI tasks have been observed in children from lower income households (Durston et al., 2002). These patterns of activity are characterized by increased prefrontal region activity overall as well as by proportionally increased activity in the dlPFC (Bruce et al., 2013; Carrion et al., 2008; Durston et al., 2002; Mueller et al., 2010; Palacios-Barrios and Hanson, 2019). Researchers have suggested that this increased activity is indicative of the increased effort/cognitive resources needed in order to perform the tasks (Bruce et al., 2013; Sheridan, Sarsour, 2012; Mueller et al., 2010). Notably, these same patterns of activation are seen when comparing younger children to adolescents and older adults (Durston et al., 2002). This makes sense, because IC processes are undergoing significant development during this period, and it is expected that performing IC tasks requires more cognitive reserve prior to maturity. For adolescents and young adults however, this pattern of activation could be reflective of relatively immature IC processes, that may be related to stunted IC maturational start points and trajectories (Casey et al., 2005). Neuroimaging research could theoretically be utilized to more definitively characterize these altered patterns of IC related brain activity in lower income children.

Future research should aim to examine whether children from impoverished environments display altered patterns of activation during IC fMRI tasks in comparison to children from less impoverished environments, including patterns of less mature activity. Such patterns would be characterized by greater activation overall, particularly in regions of the dlPFC. These altered patterns of activation may or may not be related to worse performance on the behavioral tasks but may reveal less efficient and more effortful inhibitory processes that may confer deficits in behavioral performance as IC tasks increase in complexity and difficulty. Longitudinal research should examine activation patterns over time and determine whether differential patterns are maintained across adolescence.

9. Conclusions

IC development within the context of early life poverty is an area that deserves continued targeted research. IC facilitates the development of other executive function processes, further emphasizing the importance of research in this area. Implications for later development of EF, and associated poor quality of life outcomes indicate that IC offers a prime opportunity for intervention and prevention in at-risk children. There is some evidence to suggest that IC mediates the relation between early poverty and academic achievement and externalizing behaviors. Future research should focus on examining common correlates of poverty, such as residential mobility and verbal ability as mechanisms linking early poverty and IC development. In addition, future work should incorporate neuroimaging in order to determine whether individuals may be using more inefficient, immature processes that are not necessarily captured by behavioral tasks.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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