
Learning: Research and Practice

ISSN: 2373-5082 (Print) 2373-5090 (Online) Journal homepage: https://www.tandfonline.com/loi/rlrp20

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LEARNING: RESEARCH AND PRACTICE
2019, VOL. 5, NO. 2, 99–125
https://doi.org/10.1080/23735082.2019.1674907

# Will the future BE POSITIVE? Early life experience as a signal to the developing brain *pre* school entry

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**ABSTRACT**
We suggest that prior to school entry, our earliest "teachers" and "learning settings" —that is, our parents, caregivers, and homes—provide signals about our environmental conditions. In turn, our brains may interpret this information as cues indicating the types of environments we will likely face and adapt accordingly. We discuss ways in which two such early-life cues—bilingual exposure and sensitive caregiving quality, influence "domain general" neurocircuitry and associated functioning (e.g., temperament and emotional reactivity, emotion regulation, relational memory, exploratory play, and executive functioning), as well as pre-academic outcomes. We conclude by discussing the need for early upstream intervention programmes, as well as the need for additional research including our upcoming "BE POSITIVE" study, designed to help bridge the gap between the community, home, and school environments.

**ARTICLE HISTORY**
Received 26 December 2018
Accepted 26 September 2019

**KEYWORDS**
Brain; infancy; preschool; caregiving; language

## Introduction

What impacts learning? Teachers? Schools? Curriculum quality? As educators, we may often see the impact of such influences. Yet, *pre* school entry (e.g., prior to six to seven years), the brain has already changed an enormous amount (Dean et al., 2015; Giedd et al., 2009; Gilmore et al., 2012; Holland et al., 2014; Uda et al., 2015; Uematsu et al., 2012). This early life ability for neural change, or neuroplasticity, may have arisen because humans have historically lived in a variety of diverse and ever changing conditions (Del Giudice, Ellis, & Shirtcliff, 2011). Neuroplasticity allows for "conditional adaptation" – or the ability for an individual brain to develop in accordance with the particular environment it faces (Belsky, 2000; Belsky, Steinberg, & Draper, 1991; Boyce & Ellis, 2005).

Unfortunately, we cannot know exactly what the future holds. Perhaps because the neural organisation requires a commitment of biological resources, our brains do not remain equally susceptible to environmental fluctuation across development. In order for the young brain to maximise its chances of developing in a manner consistent with future

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needs, it may therefore pay special attention to the signals that, over the course of human history, have been most reliably tied to environmental demands (see, e.g., Gluckman, Hanson, & Beedle, 2007).

Experience-expectant stimuli are stimuli that are likely for all members of a species except in exceptional circumstances. Sometimes these stages have tight boundaries, and are referred to as *critical periods*. In other cases, research investigates *sensitive* or *optimal periods*, or stages of development when environmental exposure (or lack thereof) is likely to make the greatest impact (see Werker & Tees, 2005). In addition, work with humans, using different methodological strategies (e.g., Zeanah et al., 2003), has examined the impact of exposure to other aspects of species expectant stimuli. Additional aspects of human experience-expectant stimuli are thought to include basic nutrition, basic linguistic stimulation, and access to a caregiver (Nelson, Fox, & Zeanah, 2014).

In addition to *experience-expectant* stimuli, *experience-dependent* stimuli are also considered important to brain development. For example, while all young humans are expected to receive linguistic input, the type, frequency, and nature (e.g., tonal, click, phonetic) of input likely varies according to geographical location and culture. Likewise, while all infants are expected to have basic access to a caregiver, the quality and amount of received care may greatly differ. Next, we review relations between two experience-dependent exposures, linguistic variation and caregiver quality, and young children's development in a variety of domain general (see Table 1 for examples of domain general specific skills and associated neurocircuitry) and academic domains.

## Variation in linguistic exposure

In their 2005 review paper Werker and Tees (2005) present ample evidence that human infants preferentially attend to "human speech" sounds, and can distinguish between a wide variety of such sounds; yet, by 12 months of age the infant brain reorganises in relation to the specific type of speech encountered. During the first year of life, infants demonstrate, via behaviour and electrophysiology, that they can differentiate between perceptual properties of speech stimuli, regardless of whether those properties are relevant to their current environment. Starting around 12 months, such differentiation is more limited to stimuli that they regularly encounter. Furthermore, Werker and Tees (2005) suggest that while early life exposure to a given language is important, at least some minimal exposure in later development may be necessary for the eventual adult brain to distinguish relevant perceptual aspects. Such work, then, suggests that the infant brain develops in accordance with expectations concerning the future (linguistic) environment, but tweaks its developmental course in relation to subsequently encountered information.

For an example of linguistic variation in the environment and the way it influences development, we highlight bilingualism as it is prevalent around the world, and may continue to increase with globalisation and immigration. Moreover, from an environmental signalling standpoint, exposure to multiple languages may suggest that the developing child is likely to encounter a variety of social, cultural, and linguistic experiences. Compared to monolingual children, bilinguals may need to notice, sort, parse, and compute information from two or more parallel language systems, and perhaps cultural schemas (Peal & Lambert, 1962). Differences in both neural and behavioural development may thus be expectable.

Similar to the behavioural and electrophysiological work mentioned above, magnetic resonance imaging (MRI) studies have noted an impact of bilingualism on brain functioning (Costa & Sebastián-Gallés, 2014). Notably, bilingual and monolingual infants were found to recruit similar language-specific brain areas for language processing: the left superior temporal gyrus for phonetic processing, and the left inferior frontal cortex for meaning retrieval and syntactic and phonological pattern processing (Petitto et al., 2012). However, the two populations differentially responded to Hindi-language contrasts. Ten to 12 month-monolingual infants only exhibited activation of left inferior frontal cortex to native contrasts (i.e., English), while their bilingual (but non-Hindi exposed) counterparts demonstrated significant activation to both native and non-native (i.e., Hindi) contrasts.

Bilingual exposure also relates to brain structure. Both early and late high-proficient bilinguals are reported to have increased grey matter volume in left parietal structures (verbal fluency task-related area; Mechelli et al., 2004), increased Heschl Gyrus volume (auditory processing related area; Ressel et al., 2012), and increased left putamen grey matter density (phonological processing related area; Abutalebi et al., 2013). Furthermore, in their examination of 8 to 11-year-olds, Mohades et al. (2012) found differences in microstructure organisation within two white matter tracts (i.e., the left inferior occipitofrontal fasciculus and the anterior part of the corpus callosum) amongst simultaneous bilingual, sequential bilingual, and monolingual children.

Interestingly, bilingual exposure may also relate to neural circuits important to cognitive control (Grady, Luk, Craik, & Bialystok, 2015; Heidlmayr, Hemforth, Moutier, & Isel, 2015). Increased language processing demands in bilingual children have been found to associate with other aspects of cognitive and socio-emotional development (Barac, Bialystok, Castro, & Sanchez, 2014; De Houwer, 2015). Considering that children growing up in monolingual versus bilingual environments face different challenges, this may not be surprising. For example, the bilingual environment demands a need for switching between linguistic demands (Peal & Lambert, 1962). Likewise, dual language proficiency has been found associated with enhanced executive functioning abilities in children such as set shifting and the ability to inhibit irrelevant and/or conflicting information (Bialystok, Craik, & Luk, 2012; but see Paap & Greenberg, 2013; Paap & Sawi, 2014). Specifically, bilinguals' linguistic experiences (e.g., the length of dual language usage and the frequency of codeswitching) have been linked to comparatively better performance on inhibitory control (Bialystok, 2015) and cognitive flexibility tasks (Sun et al., in press).

Differences in executive control, in turn, may influence Theory of Mind, an important aspect of social-emotional development in the early years (Carlson & Moses, 2001). In particular, some research has shown that bilingual children outperform their monolingual peers in understanding representations and false beliefs (Barac et al., 2014; but see Liu, Wellman, Tardif, & Sabbagh, 2008 for evidence to the contrary). The superior performance of bilingual children on reality questions in Theory of Mind tasks has been specifically linked with their inhibitory processing abilities (Bialystok & Senman, 2004; Kovács & Mehler, 2009). From a sociolinguistic perspective, higher dual language proficiency and longer dual language usage may also facilitate other aspects of social emotional development (Han, 2010; Sun et al., 2018).

However, in keeping with the idea that individuals prioritise skills that are most likely to be adaptive within their environments, bilingualism does not universally predict "better" outcomes in all domains across all stages of development. Although both monolingual and bilingual children go through milestones in language development (e.g., babbling, signs of language comprehension, first words, multiple words, short sentences) in the same order and at around the same age ranges (Clark, 2009; De Houwer, 2015), the manner in which they learn to label objects may differ. For example, when shown a known object and an unknown object while listening to an unknown word (Markman & Wachtel, 1988), monolinguals looked longer at the unknown object, guided by a mutual exclusivity heuristic, possibly assuming that one object can only have one label. In contrast, bilingual children looked at both objects for similar durations (Byers-Heinlein, Fennell, & Werker, 2013; Byers-Heinlein & Werker, 2009), potentially suggesting that bilinguals are familiar with the idea that each object could be linked to two labels in two languages.

Additionally, in their learning of number words (e.g., one, two, three), bilingual children show a developmental trajectory that is similar to that of monolingual children in their primary language. However, number word knowledge may not immediately transfer from their primary to secondary language (Wagner, Kimura, Cheung, & Barner, 2015). Studies from multiple laboratories have shown that number word learning follows a particular sequence (Barner, Libenson, Cheung, & Takasaki, 2009; Cheung & Ansari, in press; Le Corre, Li, Huang, Jia, & Carey, 2016; Le Corre, Van de Walle, Brannon, & Carey, 2006; Wynn, 1990). Children count as early as age 2, but they take a few years to learn the meaning of the first few number words (*one, two, three*, and sometimes, four). For example, using the Give-A-Number task in which children are asked to give a puppet a certain number of toys, researchers found that, when asked to give Mr Monkey one banana, two-year-olds may give a random number of bananas, suggesting that they do not know the meaning of *one*. A few months later, they can generate a set of one object, but they fail on *two* (e.g., giving monkey three or more bananas when asked for *two*). This number-word learning trajectory continues until the number word *three* or *four*. That is, children slowly learn the meanings of *one, two, three (*and sometimes *four*), one at a time, over the course of two to three years. Bilingual children show the same learning sequence in their primary language (Wagner et al., 2015), but the difficulty with learning number words is potentially amplified because number word meanings may be acquired separately in each of their respective languages. Indeed, in a recent study, Wagner et al. (2015) found that number word knowledge did not transfer between languages in bilingual children. They found that bilingual children who show knowledge of number words in their dominant number language do not show the same level of understanding in their secondary language. For example, an English-Spanish child who understood the meaning of *two* in English (dominant language) did not necessarily know the meaning of *dos* in Spanish (less dominant language). An interesting area of future research will be to determine whether early bilingual exposure predicts later mathematical development in a variety of cultures.

In sum, early life variation in language exposure may shape a variety of developmental outcomes prior to children entering school – or even childcare or preschool. Although in the above section we focused on bilingualism as an example of the way experience-dependent environmental variation may impact child development, other aspects of language usage may also associate with outcomes. Maternal and paternal speech (Hart & Risley, 1995), maternal lexical richness and syntactic complexity (Hoff & Naigles, 2002), maternal vocabulary diversity (Pan, Rowe, Singer, & Snow, 2005), and the density of sophisticated words uttered by mothers in the home (Weizman & Snow, 2001) all predict later outcomes. In the subsequent section, we will address additional aspects of experience-dependent exposures and child development prior to entry into educational settings.

## Variation in the degree of sensitive caregiving

As discussed, there may be sensitive periods during which the brain is especially influenced by bilingual exposure (Werker & Tees, 2005). Likewise, there may be sensitive periods during which children are particularly influenced by the quality of certain aspects of received caregiving. In this section, we focus on the influence of early-life maternal sensitivity upon the developing brain.

Maternal sensitivity is observed when mothers notice and contingently and appropriately respond to their children's cues (Ainsworth, 1967). Similar to the associations observed between maternal protective behaviour and rank in nonhuman primates (Holekamp & Smale, 1991), across a variety of human cultures maternal sensitivity is reliably linked to social status (Heng et al., 2018; Mesman, van Ijzendoorn, & Bakermans-Kranenburg, 2012; Perry et al., 2018), which is, in turn, associated with stress and/or access to resources (Dickerson & Kemeny, 2004). The degree of maternal sensitivity during early life, then, may be an especially important signal to the young child, concerning his/her family's status, and so the likelihood that he/she will encounter concurrent and future adversity. As with the infant's brain that can adapt to a monolingual or multilingual environment, the human brain may also adapt to low risk or adverse environments, as signalled by early life care. Infants exposed to lower quality care may be expected to show conditional adaptation – or to preferentially develop neurocognitive skills that allow for success in comparatively harsh environments, whereas infants exposed to more sensitive care may preferentially develop neurocognitive strategies for environments that society considers to be positive or optimal (for discussions concerning conditional adaptation see Belsky, 2000; Belsky et al., 1991; Boyce & Ellis, 2005; Del Giudice et al., 2011; Ellis, Bianchi, Griskevicius, & Frankenhuis, 2017; Ellis, Boyce, Belsky, Bakermans-Kranenburg, & van IJzendoorn, 2011).

As with humans, there are forms of rodent behaviour associated with limited resources and increased danger. In rodents, variation in these forms of maternal care predicts offspring outcomes that may be adaptive in times of adversity (Beery & Francis, 2011; Cameron et al., 2005), including increased long-term potentiation during times of alarm (the cellular process underlying memory) (Bagot et al., 2009), enhanced fear conditioning ("memory for danger"), and increased "freezing" behaviour ("reactivity to danger") (Champagne et al., 2008). However, in rodents, similar maternal behaviour also limits offspring learning and memory under less adverse conditions (Bagot et al., 2009; Champagne et al., 2008). Likewise, such maternal rodent behaviour impacts offspring endocrine responses to threat, and predicts differential patterns of neuroanatomical growth, especially within circuitry essential to stress regulation (Francis, Champagne, Liu, & Meaney, 1999). In particular, regions important to stress regulation like the hippocampus, amygdala, and prefrontal cortex are impacted by prior experience with stress, including variation in maternal care (McEwen, Nasca, & Gray, 2016). These frontolimbic structures, and their development are also important to autobiographical and relational memory, thinking about the future (Hassabis, Kumaran, & Maguire, 2007), stress and emotion regulation (Frank et al., 2014; Khalili-Mahani, Dedovic, Engert, Pruessner, & Pruessner, 2010), flexibility and perspective taking, and/or the detection of inconsistencies (Miller & Cohen, 2001).

Not surprisingly then, some of the current paper's authors have, in collaboration with other researchers, found associations between sensitive maternal caregiving in human infants and the development of neurocircuitry linked to these abilities in conditionally adaptive ways. For example, some of our work suggests that young infants exposed to lower levels of maternal sensitivity may prioritise the development of abilities that help them remember danger and act accordingly. That is, controlling for brain development at birth, infants exposed to insensitive early life caregiving show accelerated hippocampal development (Rifkin-Graboi et al., 2015), with similar correlates observed later in childhood (Bernier et al., 2019). In addition, they show greater connectivity between the hippocampus and other memory regions (Rifkin-Graboi et al., 2015), and enhanced memory (Rifkin-Graboi et al., 2018). However, in early infancy, we have also observed that connectivity between the hippocampus and the prefrontal cortex is reduced (Rifkin-Graboi et al., 2015). This is important because while the hippocampus is essential to remembering the context in which danger occurs, "fear extinction" – or learning required to shift behaviour when conditions have changed – requires both hippocampal and prefrontal cortex involvement (Milad et al., 2007). Indeed, we have found that preschoolers who were exposed to lower levels of maternal sensitivity in infancy are comparatively less likely to reduce their startle response after repeated exposure to a mildly frightening stimulus (Tsotsi et al., 2018). Likewise, others have found that in certain contexts exposure to lower levels of maternal sensitivity in infancy associates with behavioural disorganisation (e.g., freezing) during moderate distress in toddlers (reviewed in Bernier & Meins, 2008).

In addition, others' research links sensitive caregiving to infants' abilities to flexibly balance the competing demands of seeking comfort and engaging in exploration (Main, 2000). This association between sensitive caregiving and balanced exploration and attachment is consistent with the Surplus Resource Theory (Burghardt, 2005), which states that exploratory play can only evolve when there is surplus resources from parents (e.g., safety and provisioning).

Taken together then, research suggests that exposure to low levels of maternal sensitivity (Atkinson et al., 2013; Blair, Granger, Willoughby, & Kivlighan, 2006; Bosquet Enlow et al., 2014), or other environmental signals that the future environment will likely be harsh, uncontrollable, or exclusionary (Dickerson & Kemeny, 2004; Rifkin-Graboi, Borelli, & Bosquest, 2009), associates with a cascade of neurochemical processes that may ultimately influence regions like the hippocampus, amygdala, and prefrontal cortex, and result in behaviour that is adapted to prioritise memory for danger, discount the role of positive information, limit complex exploratory behaviour, be sensitive to external threats, and take longer to reverse fear learning. However, as with Bagot et al.'s (2009) rodent work, such adaptation likely comes at a cost. Indeed, a plethora of research also suggests that insensitive care and/or the highly associated construct of insecure attachment negatively predicts aspects of development that may be beneficial in lower stress conditions, including most modern classrooms: lower levels of externalising behaviour and friendship formation (Groh, Fearon, IJzendoorn, Bakermans-Kranenburg, & Roisman, 2017), attentional focus (Fearon & Belsky, 2004), flexibility in shifting between rules and the ability to inhibit actions and thoughts (Bernier, Carlson, Deschenes, & Matte-Gagne, 2012; Matte-Gagne, Bernier, Sirois, Lalonde, & Hertz, 2018), language development (Paavola, Kemppinen, Kumpulainen, Moilanen, & Ebeling, 2006), and fear regulation (Tsotsi et al., 2018). Likewise, preschool children's Theory of Mind (ToM) can be predicted from maternal mind-mindedness and attachment security during infancy (Meins et al., 2002), mother's mental state language (Ruffman, Slade, & Crowe, 2002), and family parenting styles (Pears & Moses, 2003). Not surprisingly, then, attachment is also associated with academic achievement (Dindo et al., 2017; Moss & St-Laurent, 2001)

Nevertheless, not all children may be equally influenced by variance in caregiving quality. The goodness-of-fit model suggests that a "fit" between child-rearing practices and child temperament predicts more favourable child outcomes (Thomas & Chess, 1977). For example, amongst fearful children measures of morality associate with parental gentle disciplinary strategies, whereas within unfearful children, warm and responsive yet firm parenting associates with moral outcomes (Kochanska & Aksan, 2006). Furthermore, initial evidence suggests that existing variation in brain structure may influence the extent to which insensitive caregiving predicts behavioural disorganisation during laboratory distress (Rifkin-Graboi et al., 2019).

Likewise, although much of the animal research examining caregiving relies on cross-fostering and/or the experimental induction of adversity, limiting the extent to which the resulting outcomes may be considered entirely due to genetic similarities between mothers and offspring (Meaney & Szyf, 2005), genetics are, nevertheless, likely to play a role in child outcomes (e.g., Luijk et al., 2011). Children with particular genetic backgrounds and/or of particular temperaments may be more susceptible to variation in caregiving behaviour (e.g., see Belsky, 2000). For instance, infant irritability or reactivity can lead to particularly positive outcomes in response to supportive and enriching experiences, but can also result in negative outcomes in aversive environments (Belsky, Bakermans-Kranenburg, & van Ijzendoorn, 2007; Belsky & Pluess, 2009). As with other work examining genetic and environmental influences on brain development (Ong et al., 2019), both observational and interventional studies that examine the impact of enhancing sensitive parenting, suggest that genetic factors can influence the degree to which parents and children are influenced by environmental adversity, including insensitive care (Bakermans-Kranenburg, van IJzendoorn, Mesman, Alink, & Juffer, 2008; Bakermans-Kranenburg, van IJzendoorn, Pijlman, Mesman, & Juffer, 2008; Van Zeijl et al., 2006).

Still, the influence of genetic factors on environmental susceptibility to signals of environmental adversity does not imply that variation in specific forms of caregiving is irrelevant (Belsky, 2000). Interventions aimed at enhancing caregiving sensitivity not only alter child outcomes, they are also as or even more effective than parenting interventions specifically designed to enhance children's (pre) academic outcomes in the domains of executive functioning (Lewis-Morrarty, Dozier, Bernard, Terracciano, & Moore, 2012), stress physiology (Dozier, Peloso, Lewis, Laurenceau, & Levine, 2008), and language development (Bernard, Lee, & Dozier, 2017). These interventional studies therefore suggest specificity in the mechanisms linking adult and child behaviour, as well as malleability in the behaviours themselves.

In sum, a large body of research indicates that variation in early life caregiving may be an important experience-dependent influence upon child development. Differential susceptibility not-withstanding, the human brain may treat the degree of exposure to sensitive caregiving as a cue to future environmental conditions and adapt accordingly. In addition, although the above section predominantly focuses upon maternal sensitivity, other aspects of early-life parenting may also predict child outcomes, though they may not all be expected to serve as signals of environmental adversity. Parenting processes associated with child development include engagement in daily activities and the availability of play materials (Miquelote, Santos, Caçola, Montebelo, & Gabbard, 2012), the amount and type of number talk provided by parents and teachers (e.g., Gunderson & Levine, 2011; Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2011), home numeracy activities (LeFevre et al., 2009; Skwarchuk, Sowinski, & LeFevre, 2014), parental responsiveness and stimulating play (Bradley et al., 1989), and parental mindfulness (Campbell, Thoburn, & Leonard, 2017; Parent, McKee, Rough, & Forehand, 2016; Singh et al., 2006, 2007; Siu, Ma, & Chui, 2016).

## Creating a positive environment: next steps for interventions and research

Throughout this review, we have urged the reader to consider child behaviour through an adaptive lens. Though distractibility, perseveration, heightened threat detection and arousal, and prolonged distress or wariness, are often not considered “skills” in the childcare, preschool, or school environments, such abilities may represent conditional adaptation to signals of a harsh environment often mediated through low levels of sensitive caregiving, limited linguistic stimulation, and poor nutrition. Thus, while we often think of children exposed to these environments as having problems – we can instead consider them to have alternative strengths (Ellis et al., 2017; Frankenhuis & de Weerth, 2013). Such a shift in mindset may open up alternative and more effective ways of teaching young children from a variety of backgrounds (Ellis et al., 2017).

Still, given the skills (e.g., good regulatory abilities, Israel et al., 2014; Moffitt et al., 2011) likely beneficial for *success* in many developed nations, it is also worth considering prevention and intervention programs aimed at altering environmental signals prior to school entry (e.g., see meta-analyses by Grube & Liming, 2018; Juffer, Bakermans-Kranenburg, & Van IJzendoorn, 2018). Furthermore, it may be of benefit to identify those at greatest need for intervention in early life so as to enhance individuals’ quality of life sooner, rather than later, and so developmental screening tools may also be of use (Bricker, Macy, Squires, & Marks, 2013). In addition, from a learner’s perspective, interventions that occur before school age alleviate the potential for social stigma that, rightly or wrongly, may accompany being part of school-based learning support. Likewise, the benefits of both intervening prior to school entry and educating childcare workers and early childhood teachers about the strengths and challenges associated with varying environmental exposures may also lead to less frustrating experiences for children, families, and educators concurrently, and in the future. Taken together, the results from child-based executive control and regulation interventions may suggest that the most effective programs are ones that address multiple aspects of well-being, interspersed through daily-life (Diamond & Ling, 2016). Such work, then, implies that, in addition to parents, child-care and preschool teachers may have the opportunity to alter developmental trajectories.

Ultimately, we must work across the community, health care, and educational contexts to produce environments that signal young brains, “Be optimistic! The future will be positive!”

and provide them with environments that are. At the same time, we must recognise that children enter school with different competencies, and so find ways to build upon their strengths to enhance classroom success (Ellis et al., 2017). As a step towards this goal, we, along with our colleagues at the National Institute of Education's Centre for Research in Child Development and SingHealth Polyclinics are working towards the launch of BE POSITIVE (**BE**dok-**P**unggol **O**ngoing **S**ingaporean study beginning in **In**fancy: **T**wenty-first century skills, **I**ndividual differences, and **V**ariation in the **E**nvironment).

This neighbourhood study of families, recruited through large health-care centres or "polyclinics," will capture the aforementioned early life exposures and children's domain general (for specific constructs, see Table 1) and pre-academic skills, in advance of school age. By repeatedly assessing the quality of the early environment we will be in a better position to make recommendations concerning when (and so relatedly how) to intervene. Because we are testing multiple general constructs, we will also be able to understand whether there are tradeoffs with regards to which skills (e.g., relational memory, executive functioning, vigilance, etc.) are prioritised. Moreover, because we will repeatedly test the same constructs, we will also be able to examine the ways environmental exposure may influence the pace at which a given skill develops. This strategy also allows for a more complete understanding of how general domain skills may influence specific academic skills and functioning over time, which is important to determine the best intervention and prevention programs. For example, consider the following two hypotheticals. In the first case, suppose we learn that the pace at which memory develops over the first two years is important to receptive semantic skills at age three, which in turn correlate with (perhaps via self-talk) emerging preschool executive functioning and (perhaps via inter-personal communication) socioemotional functioning. In this scenario it would be worth considering whether to implement aprogramme designed to speed up memory development amongst zero to two-year-olds and/or a programme designed to help zero to two-year-olds with slower developing memory skills increase the rate at which their receptive semantic skills develop. However, we would not reach the same conclusions about when to intervene if we were to find that differences in age three memory (but not the pace at which memory develops) predict age three receptive semantic skills, and in turn emerging executive and socioemotional functioning. Moreover, in cases where skills begin to develop early in the face of adversity, results from individual studies examining skills at only one or two points in time can seem nonsensical or even contradictory, making it hard to know how or when to intervene. For example, it would be nearly impossible to know what to make of the following hypothetical information: a) more parental anxiety at four months associates with worse associative memory at six months; b) more parental anxiety at four months associates with better associative memory at 24 months; c) better associative memory at six months predicts better associative memory at nine months; d) associative memory at six months has no significant association with associative memory at 18 months; e) better associative memory at nine months predicts worse mathematical functioning at four years; f) better associative memory at 18 months predicts better mathematical functioning at four years; g) better associative memory at 24 months predicts better mathematical functioning at four years. In contrast, consider the potential for intervention if these same pieces of hypothetical information were obtained as part of a larger study demonstrating the following patterns: a) children exposed to parental anxiety at four months show

**Table 1.** Domain general functions: neurocircuitry, description, and assessment.

| Domain General Function | Key Neural Regions | Description and Behavioural Assessment |
| --- | --- | --- |
| Temperament and Emotion Reactivity | Amygdala (Frank et al., 2014; Kagan & Fox, 2006; Pruessner et al., 2010) | In general, temperament refers to early emerging dispositions, in reactivity, affectivity, attention and self-regulation (Shiner et al., 2012). Although temperament may impact the degree to which the environment influences children's outcomes, temperament itself is shaped by the interactions among genetic and environmental factors across time. Genetic make-up contributes to about half of individual differences in temperament (Caspi, Roberts, & Shiner, 2004), though sociocultural influences may also play a role (Kagan et al., 1994; Lewis, Ramsay, & Kawakami, 1993; Rubin et al., 2006).<br>Temperament shows stability and continuity over time and consistency across situations (Rothbart & Bates, 2006), but there are also significant changes during development (Roberts & DelVecchio, 2000). In early childhood, changes in temperament are often measured through direct observations or parental questionnaires. For example, Jerome Kagan and his colleagues created a behavioural battery to observe infant reactivity in the laboratory (Kagan, Snidman, & Arcus, 1998). During the assessment, four-month-old infants are presented with a series of novel stimuli, such as mobile toys and unfamiliar voices. Infants who are motorically aroused and distressed in response to the novel stimuli are categorised as high reactive. Infants who display minimal motor activity and distress are categorised as low reactive. In addition to behavioural observation, parental questionnaires are often administered to learn about children's temperament across situations (Gartstein & Rothbart, 2003).<br>Temperament measured in early childhood predicts later child outcomes. For instance, infants who were classified as highly reactive were more likely to become inhibited toddlers who showed more fearful reactions when facing unfamiliar stimuli, compared to infants classified as low reactive (Kagan et al., 1998). Furthermore, as reviewed by Al-Hendawi (2013), temperament significantly predicts children's later school adjustment and academic achievements. Particularly, school adjustment is positively correlated with self-regulation, but negatively correlated with negative affectivity. Activity level (i.e., physical energy) predicts children's academic achievements, especially reading competencies. |

(*Continued*)

**Table 1.** (Continued).

| Domain General Function | Key Neural Regions | Description and Behavioural Assessment |
| --- | --- | --- |
| Emotion Regulation | Multiple regions including the amygdala and, hippocampus in interaction with the prefrontal cortex (Dixon, Thiruchselvam, Todd, & Christoff, 2017; Pruessner et al., 2010). | Emotion regulation refers to processes involved in the modulation of emotional arousal and reactivity in order to adapt to a given environment and accomplish one's goals (Cole, Martin, & Dennis, 2004; Thompson, 1994). As noted directly above, variations in emotion regulation may be attributed to inherent child attributes (e.g., temperament), but may also be influenced by the environment (Eisenberg, Spinrad, & Eggum, 2010). For example, sensitive contingent caregiving is associated with the regulation of anger, frustration (Conway et al., 2014; Feldman, Dollberg, & Nadam, 2011), and fear (Tsotsi et al., 2018) at around age three.<br>In addition, the degree to which emotion regulation relies on internal versus external factors also depends on developmental stage. In infancy, emotion regulation is often determined by caregiver-led processes (e.g., physical touch) (Cassidy, 1994; Spinrad & Stifter, 2002), along with some self-soothing behaviours, such as finger sucking (Braungart-Rieker, Garwood, Powers, & Wang, 2001). With age, children's own attentional, memory, and executive functioning abilities begin to play a role (Eisenberg et al., 2010). Increasingly, children become able to inhibit their automated responses, behave intentionally and even plan their responses (Diamond, 2002). Furthermore, across development the growing necessity for socialisation, including peer and adult expectations, drives children to respond in more sophisticated and socially appropriate manners (Bridgett, Burt, Edwards, & Deater-Deckard, 2015). Still, even at school age, the presence of an important caregiver may be important to neural functioning during an emotional regulation task (Gee et al., 2014).<br>In young children emotion regulation is usually measured through observational methods (that encompass coding of behavioural responses to given stimuli or situations), physiological changes (e.g., heart rate variability) or reports by caregivers or teachers. The Still-Face Paradigm (Tronick, Als, Adamson, Wise, & Brazelton, 1978) is one example of an observational method for infants who undergo a face-to-face interaction with their parent in three steps, i.e., a baseline interaction as usual, a "still-face" episode, wherein the parent becomes expressionless, and the return to usual interaction. Likewise, the Transparent Box task (Goldsmith, Reilly, Lemery, Longley, & Prescott, 1999) is designed to elicit frustration and calls for frustration regulation in preschoolers; it involves locking a desirable toy in a transparent box, handing the wrong set of keys to the child and asking them to open it to play with the toy. Children's expressed frustration and anger is then assessed based on their bodily movements, facial expressions, and vocalisations. Such paradigms can also be used to collect physiological data (e.g., Conradt & Ablow, 2010; Moore et al., 2009)<br>Differences in emotion regulation predicts a variety of social outcomes including peer relationships (Raver, Blackburn, Bancroft, & Torp, 1999; Séguin & MacDonald, 2016) internalising problems (Blair, Denham, Kochanoff, & Whipple, 2004; Silk, Shaw, Forbes, Lane, & Kovacs, 2006), and externalising problems (Eisenberg et al., 2001). In the school setting efficient emotion regulation skills were related to respect towards others (Miller et al., 2006), better compliance to rules (Gilliom, Shaw, Beck, Schonberg, & Lukon, 2002), and adjustment in the classroom (i.e., positive interactions with teachers and peers, participation in structured activities, language and numeracy skills; Shields et al., 2001). In addition, emotion regulation difficulties may hinder children's concentration on a given task in the classroom, further obstructing their learning (Howse, Calkins, Keane, & Shelton, 2003). |

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**Table 1.** (Continued).

| Domain General Function | Key Neural Regions | Description and Behavioural Assessment |
| --- | --- | --- |
| Relational Memory | (Shimamura, 2010) | Relational memory is an aspect of explicit or "conscious" memory and is considered essential to binding facts together – an obvious component of learning, but also important to autobiographical memory and engaging in future thinking or prediction (Richmond & Pan, 2013). As such, relational memory is important to building representations of the world, which are themselves essential to both cognitive and socioemotional schemas that guide cognition and emotion. As discussed in the text, relational memory may be influenced by parenting behaviour, and, perhaps due to the hippocampus's richness in steroid receptors, other forms of endocrine variation, including obesity (Khan et al., 2015).<br>Relational memory may begin to emerge by six to nine months of age, and in infancy is often investigated via eye tracking paradigms (Chong, Richmond, Wong, Qiu, & Rifkin-Graboi, 2015; Richmond & Nelson, 2009; Richmond & Power, 2014; but see Gomez & Edgin, 2016). For example, during an encoding phase, infants are presented with scene-object pairs. Then, during a retrieval phase the same scenes are shown, but with a multitude of objects superimposed upon them. The degree to which the infant looks at the object that was previously paired with the scene (as compared to objects that are familiar but not correctly paired) is taken as evidence of relational memory. At later stages of development tests of relational memory may also assess other aspects of behaviour including accuracy (Pathman & Ghetti, 2016).<br>Interestingly, aspects of relational memory may differ in their rate of development – with "item-space" binding reaching adult levels by age 9, item-time by age 11, but item-item not fully developed until adulthood (Lee, Wendelken, Bunge, & Ghetti, 2016). |

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**Table 1.** (Continued).

| Domain General Function | Key Neural Regions | Description and Behavioural Assessment |
|---|---|---|
| Exploratory Play | Bilateral parietal and frontal regions (Laureiro-Martínez, Brusoni, Canessa, & Zollo, 2015) | One of the first ways infants and young children explore and learn about the world is through play (Bruner, Jolly, & Sylva, 1976; Groos, 1901; Piaget, 1962). From as young as five months of age, infants start to manipulate novel objects in a way different from familiar objects, and they gather information in the process (Ruff, Saltarelli, Capozzoli, & Dubiner, 1992). This type of "exploratory play" has a pivotal role in understanding how early environment affects the development of brain and behaviour.<br>Developmental research has shown that play in general supports the acquisition of cognitive, social, and motor skills in human children (Bjorklund & Brown, 1998; Hirsh-Pasek, Golinkoff, & Eyer, 2004; Hutt & Bhavnani, 1972; Pellegrini & Smith, 1998; Singer, Golinkoff, & Hirsh-Pasek, 2006; Youngblade & Dunn, 1995). Exploratory play, in particular, has cascading effects on children's learning about the physical and social world (Libertus & Needham, 2010; Rakison & Krogh, 2012). Infants' exploratory play helps develop cognitive skills such as the understanding of goal-directed actions (Gerson & Woodward, 2014; Sommerville, Woodward, & Needham, 2005), causal reasoning (Rakison & Krogh, 2012), mental rotation (Schwarzer, Freitag, & Schum, 2013), and vocabulary learning (Ruddy & Bornstein, 1982). For toddlers and preschoolers, exploratory play has been shown to facilitate spatial cognition (Oudgenoeg-Paz, Leseman, & Volman, 2015), hypothesis testing (Legare, 2014), and forming higher-order generalisations (Sim & Xu, 2017). Longitudinal studies have further identified long-term consequences of early exploratory play. For example, Yarrow, Klein, Lomonaco, and Morgan (1975) showed that duration of exploratory play at six months predicts Binet IQ at 3.5 years. Similarly, Muentener, Herrig, and Schulz (2018) found that the efficiency of infants' exploratory play predicts vocabulary size and IQ at age 3.<br>Finally, exploratory play both predicts and serves as a diagnosis tool for developmental disorders. The clinical diagnosis of ASD and ADHD is partly based on the judgement that children engage in atypical exploratory play (e.g., restricted/repetitive play in ASD, and distracted/disorganised play in ADHD; American Psychiatric Association, 2013). Differences in exploratory play have also been found between typically developing infants and infants at risk of Downs Syndrome (de Campos, Da Costa, Savelsbergh, & Rocha, 2013; Loveland, 1987), at risk of ASD (Kaur, Srinivasan, & Bhat, 2015; Koterba, Leezenbaum, & Iverson, 2014), and those born prematurely (Sigman, 1976; Zuccarini et al., 2016). |

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**Table 1.** (Continued).

| Domain General Function | Key Neural Regions | Description and Behavioural Assessment |
|---|---|---|
| Executive Functioning (Working memory, set shifting, and inhibition | Fronto-parietal network, basal ganglia, thalamus, caudate, cerebellum (working memory);<br>dorsolateral prefrontal cortex (set shifting); anterior cingulate cortex, ventrolateral prefrontal cortex, right inferior frontal cortex (inhibition) (Aron, Robbins, & Poldrack, 2004; Eriksson, Vogel, Lansner, Bergstrom, & Nyberg, 2015; Miller & Cohen, 2001) | Likened to an air traffic control system, executive functions (EFs) support adaptive, goal-directed behaviours. EF primary functional groups are often considered to be working memory (monitoring, manipulating and updating information), inhibition (resisting inappropriate prepotent responses/impulses or interference from irrelevant information), and shifting (mental set shifting; also termed switching or cognitive flexibility) (Diamond, 2013; Miyake et al., 2000). Executive functioning is essential to self-regulating thoughts, emotions, and actions. Executive functioning underlies a broad range of skills and behaviours on all levels including acquiring a motor schema like cycling, staying focused and engaged in a task, resisting temptations and distractions, regulating stress and negative affect, sustaining play and interpersonal relations, resilience, and physical and mental well-being (Diamond, 2013). Self-regulation may also be referred to with terms such as "self-control" (Moffitt et al., 2011) and has been regarded "a key to success in life" (Baumeister, Leith, Muraven, & Bratslavsky, 2002, p. 117). As discussed in the text, EF associates with differential maternal care, stress hormone exposure, and bilingualism.<br>Early self-regulation has been found to predict later outcomes such as achievement, health and economic standing, and quality of life – even more so than IQ or socioeconomic status (e.g., Moffitt et al., 2011). Executive functions have been found to be more important for school readiness than IQ or entry-level reading or maths, and to predict success throughout school (preschool through university) in diverse areas (see e.g., Diamond & Ling, 2016), including social functioning (e.g., Diamantopoulou, Rydell, Thorell, & Bohlin, 2007) and moral development (Kochanska, Murray, & Coy, 1997). Executive function deficits are often associated with neurodevelopmental disorders, such as Attention Deficit Hyperactivity Disorder (ADHD) and Autism Spectrum Disorders (ASD), and learning disorders, such as in language and mathematics (Gathercole, Alloway, Willis, & Adams, 2006; Geary, 2003).<br>Tests of EF typically separately measure working memory, inhibition and shifting. Tasks for adults and older children are often computerised; administrations for very young children may involve the use of concrete materials (such as cards) to present age-appropriate stimuli (e.g., pictures of animals), and tend to be shorter and less complex.<br>While a task for a three-year-old may look slightly different from that administered to a twenty-year-old, much research has gone into creating paradigmatic tasks/batteries that can measure EF constructs across most of the lifespan. For instance, the NIH Toolbox (NIHTB) provides versions of similar EF tasks appropriate for individuals from 3–85 years of age (Weintraub et al., 2013). However, while tasks assessing separate EF components can be administered to children as young as two to three years of age, developmental studies have suggested that the separation among EF components are less distinct in early childhood (see Lee, Bull, & Ho, 2013). |

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**Table 1.** (Continued).

| Domain General Function | Key Neural Regions | Description and Behavioural Assessment |
|---|---|---|
| | | Tasks for children below the age of three tend to look quite different from adult versions, and may reflect global EF rather than respective components. For instance, in the A-not-B/delayed-response task, an infant watches a desired object being hidden in one of two places (left/right) and is encouraged to reach for the hidden object after a few seconds' delay. In order to find the object, the infant needs to engage his/her memory to hold and update information concerning the most recent object location, and resist proactive interference from irrelevant location information from previous trials. As the infant is rewarded for each correct reach (by obtaining the desired object), the action of reaching to that particular location is reinforced, increasing the prepotency of the reaching response to that location. When the hiding location is switched, the infant must then inhibit the prepotent tendency to reach to the previously rewarded location and respond according to the most updated mental representation. Infants show improvement on this task between 6 to 12 months, reflecting development in EF (Diamond, 2002). At even younger ages (e.g., 3.5 months), looking behaviours (e.g., looking duration and visual anticipation) measured via eye tracking (Haith, Wass, & Adler, 1997; Posner, Rothbart, & Thomas-Thrapp, 1997; Quan et al., 2017) and reaction time have been taken to reflect attentional capabilities and efficiency of information processing, found to correlate with regulatory abilities (Diaz & Bell, 2011) and later speed of processing and IQ (age 4) (Dougherty & Haith, 1997). |
| Theory of Mind | Medial prefrontal cortex, temporoparietal junction (Gallagher et al., 2000; Saxe, Whitfield-Gabrieli, Scholz, & Pelphrey, 2009) | Theory of Mind (ToM) refers to children's understanding of their own and others' minds, and is a foundational social cognitive skill that draws interest of researchers from different disciplines (Carlson, Koenig, & Harms, 2013). It is often linked to executive functioning as it requires "switching" perspectives and holding multiple thoughts in mind (Carlson & Moses, 2001). ToM deficits (Baron-Cohen, Leslie, & Frith, 1985) are often present in those with ASD.<br>Still, for most children, ToM develops in a stable, predictable sequence (Wellman, Cross, & Watson, 2001). Before their second birthday, infants typically understand that people have different desires (Repacholi & Gopnik, 1997), and their actions are goal-directed (Woodward, 2009). However, it is not until preschool years when children show adult-like understandings of other's beliefs. For example, children below three years of age typically have difficulty understanding that people can believe something that is false ("false belief"), such as Sally believing a marble to be in its original location even though in reality it has been moved unbeknownst to her (Wimmer & Perner, 1983). Newer methods using looking time measurements have revealed early forms of false belief reasoning even in infancy (Baillargeon, Scott, & He, 2010), though whether infants' looking time truly reflect an understanding of ToM remains a controversial topic (Dörrenberg, Rakoczy, & Liszkowski, 2018). To date, the Theory of Mind Scale (Wellman & Liu, 2004) remains the standard measurement for ToM development in verbal children.<br>ToM is related to parent-child relationships (Meins et al., 2002). In addition, there are close relations between the development of ToM and language (Milligan, Astington, & Dack, 2007), executive function (Carlson & Moses, 2001), and pretend play (Taylor & Carlson, 1997). ToM development also has long-term implications for children's cognitive and social functioning, such as social competence, peer acceptance, and early success in school (Astington & Pelletier, 1998; Dunn & Cutting, 1999). |

a comparative acceleration in the development of memory abilities, performing better at four months of age than their counterparts; b) however, by 18 months of age, the memory skills of those exposed to lower levels of anxiety have "caught up," and by 24 months begin to exceed their higher-anxiety-exposed counterparts; c) in addition, both parental anxiety and child memory capabilities predict four year mathematical functioning; d) when controlling for parental anxiety, associative memory positively predicts maths. With the latter hypothetical longitudinal set of findings we can begin to think about a multi-pronged approach for children at risk for mathematical problems: determine whether caregivers are high on anxiety and address this; amongst children with parents low on anxiety, consider possible ways to boost associative memory; amongst older infants with parents high on anxiety, consider ways to capitalise on the early-emergence of advanced associative memory and decrease child anxiety by, for example, engaging in fun maths games.

Finally, because BE POSITIVE is centred in the community, we anticipate an increased likelihood that the BE POSITIVE children will ultimately cluster in neighbourhood preschools and schools. If this does indeed occur, it will provide a unique opportunity to study the interactive effects of the home, school, and peer-group. As such, we will better understand the complex interactions between early life signals of expectable environments and later functioning in the real environments children eventually encounter.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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