

## COMMENTARY

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# Moulding environmental contexts to optimise neurodiverse executive function performance and development: A goodness-of-fit account

Alexandra Hendry  | Gaia Scerif

Department of Experimental Psychology,  
University of Oxford, Oxford, UK

**Correspondence**

Alexandra Hendry, Department of  
Experimental Psychology, University of  
Oxford, Oxford, UK.  
Email: [alexandra.hendry@psy.ox.ac.uk](mailto:alexandra.hendry@psy.ox.ac.uk)

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**Abstract**

Executive functions (EFs) provide a top-down response to stimuli and events in pursuit of a goal. We argue that the extent to which an individual's environment is enriching and a good fit for them influences whether their performance at that moment is towards their upper- or lower-limit of EF ability. We outline the implications of this for interpreting measures of EF. We next argue that a child's sensitivity to the environment, and their caregivers' ability to modulate the environment to improve goodness-of-fit, influences the cumulative effects of the environment in shaping that child's actualised EF ability (the performance level shown in day-to-day situations), and thus their skill development. We therefore recommend that EF interventions be designed to improve children's actualised EF ability by improving their day-to-day environment, while simultaneously helping children modulate their physiological response to environmental challenges, and providing opportunities to practise EF skills in ecologically-valid contexts.

**KEYWORDS**

environment, executive function, goodness-of-fit, neurodiversity

Executive functions (EFs) are higher-order cognitive skills that enable individuals to provide an adaptive, top-down response to the changing demands of the environment, in pursuit of a goal. EF skills include the ability to control one's impulses, ignore distracting stimuli, hold relevant information in mind, and shift between competing rules or attentional demands, in adults (Friedman & Miyake, 2017), children (Obradović et al., 2019), and infants (Hendry et al., 2016).

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EFs are widely considered to be domain general; acting on, but separable from, other cognitive processes (Camerota et al., 2020; Miyake & Friedman, 2012; Zelazo & Carlson, 2023). Indeed, researchers often deploy modelling techniques to compute a measure of EF that is separable from the 'measurement noise' associated with the sensory, language or motor demands, or the specific motivational qualities and prior knowledge requirements of any single EF task (Camerota et al., 2020; Karr et al., 2018).

Yet, the deployment of EFs is also context-specific. Doebel (2020) has argued convincingly for the importance of considering how EFs are embedded within, and contingent upon, individuals' knowledge, beliefs, norms, values, and preferences, while Holochwost and colleagues have underscored the importance of disentangling stable, trait-like EF capacity from intra-individual, context-specific, state-like EF performance (Holochwost et al., 2023). Here we extend this reasoning to argue that an individual's EF ability at any moment in time may be anywhere within the range of their personal lower- and upper-limit EF ability, depending on context. An individual's *upper-limit EF ability* is the performance level they show when conditions are optimum (or would show if given that opportunity), and is constrained by an individual's embodied capabilities, which in turn are influenced by genetics, age, nutrition, and experience. An individual's *actualised EF ability* is the modal performance level they show in day-to-day situations relevant to that behaviour.

Below, we outline how the environment, the individual child, and their caregivers, influence whether an individual's actualised EF ability is closer to their upper- or lower-limit EF ability, and how this may impact developmental trajectories. We then outline the implications of this line of reasoning for development and interpretation of EF measures, and for intervention design.

## 1 | THE ENVIRONMENT CONSTRAINS INDIVIDUALS' ACTUALISED AND UPPER-LIMIT EF ABILITY

The environment can constrain EF performance in ways that are subtle and transitory, or pervasive and far-reaching. Take, for example, the impact of noise: Studies have demonstrated that acute noise exposure (e.g., from road traffic, aircraft, classroom noise or babble) can negatively impact sustained attention and EF performance in children; that is, noise causes children to perform closer to their lower-limit EF than would otherwise be the case (Bhang et al., 2018; Fernandes et al., 2019; Vettori et al., 2022)—although null and even positive effects of noise have also sometimes been observed, see Mealings (2022) for a review. For many children, exposure to noise is more than an experimental manipulation, it is part of their day-to-day experience. The logical consequence of persistently performing close to one's lower-limit EF is that one's EF skills develop more slowly. Accordingly, aircraft noise has been demonstrated to have chronic negative effects on children's attention and EF performance (van Kempen et al., 2010), while exposure to road-traffic noise is associated with higher parental report of attentional difficulties (Weyde et al., 2017), slower development of working memory (Foraster et al., 2022), and lower teacher-rated EF scores for boys specifically (Belojevic et al., 2012). The negative effects of noise on EF performance and development are generally considered to be attributable to some combination of the increased attentional load required to ignore task-irrelevant sounds (Elliott, 2002), and the stress-inducing nature of distracting, aversive or annoying sounds (Stansfeld et al., 2005; Trimmel et al., 2012).

Of course, noise is by no means the only type of stressor experienced by children. Exposure to adverse childhood experiences such as violence, injury and threat has also been shown to influence EF development (Lund et al., 2020). As with noise, exposure to adverse childhood experiences may disrupt actualised EF in the moment, by pulling attention away from the task in hand, and by exerting more-pervasive effects on the neural substrates supporting EF (and thus upper-limit EF ability) via physiological responses to stress involving neurotransmitters, hormones and receptors within limbic-to-prefrontal cortex circuitry (Arnsten, 2009; Danese & McEwen, 2012; Kolb et al., 2017), and the hypothalamic–pituitary–adrenal axis (Danese & McEwen, 2012; Plieger & Reuter, 2020). Note that the effects of stress are not necessarily linear; optimum EF performance is sometimes observed at moderate levels of stress, arousal or exposure to emotional or cognitive challenge (Arnsten, 2009; Finch & Obradović, 2017) and moderate variability in cortisol around a low average level is associated with higher EF ability in children

(Blair & Berry, 2017). Nevertheless, McLaughlin and others have identified stress as a key mechanism within what they term the threat-adversity pathway linking Adverse Childhood Experiences to lower EF and other cognitive outcomes (McLaughlin et al., 2014). Here, we propose that, even for those children not exposed to Adverse Childhood Experiences, or disruptive or hostile surroundings, variation in their environments will impact on their ability to perform at, and thus practise and extend, their upper-limit EF ability.

Extensive evidence indicates that childhood EFs are positively associated with access to resources and enriching interactions in the home (Hendry et al., 2022; Jasińska et al., 2022; Koşkulu-Sancar et al., 2023) and school or Early Childhood Education and Care setting (Davies et al., 2021; Koşkulu-Sancar et al., 2023; Vandenbroucke et al., 2018). Sheridan, McLaughlin and others have suggested that access to resources and enriching interactions can be considered in terms of a deprivation-enrichment scale, where at the one end children are deprived of the complex cognitive and social inputs (and perhaps moderate stressors) required for optimum cortical development, and at the other end children are exposed, with the support of responsive caregiver(s), to a range of sensory inputs, rich language and reciprocal interactions, and appropriate cognitive and physical challenge (Sheridan & McLaughlin, 2014). Variation in deprivation-enrichment exposure may exert influence over EF via a different mechanism to the threat/adversity pathway, perhaps relating to the experience-dependent development of an optimal balance between short- and long-range synaptic connections (Fair et al., 2007).

## 2 | INDIVIDUAL DIFFERENCES IN RESPONSES TO THE ENVIRONMENT: A FOCUS ON NEURODIVERSITY

The impacts of the child's environment(s) on their EF performance and development are by no means deterministic however, due to the dynamic interactions between each individual child and their environments. Many researchers have argued that children differ in their biological susceptibility to environmental influences (Ellis et al., 2011; Obradović et al., 2010; Raver et al., 2013), such that the impacts of threat/adversity and deprivation/enrichment on a child's ability to perform at their upper-limit EF ability may be greater for some children than others. More broadly, a child for whom a broad range of environments fits their needs and preferences, or who is less sensitive to external stressors or distractors, is more likely to often find themselves able to demonstrate their upper-limit EF ability compared with a child who has a very narrow window of optimum conditions and/or whose optimum conditions does not overlap with societal norms. Consequently, the difference between actualised EF ability and upper-limit EF ability varies from child to child (Dirk & Schmiedek, 2016, 2017; Yu et al., 2021).

Neurodivergent children are likely to be over-represented in the group of children whose preferred environment(s) does not regularly overlap with the environments to which they are exposed. Classroom environments and social norms in the Global North tend not to fit the attentional style and movement needs of children with ADHD (Russell et al., 2022), while sensory hyper-sensitivity is common for autistic children, such that certain sounds, sights or smells, which may be common in the school environment, are painful or overwhelming (Ben-Sasson et al., 2019; Laurent & Fede, 2021; Williams et al., 2019). The implication here is that the cumulative effects of poor environmental fit mean that neurodivergent children are more likely to be regularly performing at their lower-limit EF ability, particularly while at school, thereby constraining further learning and development. Teacher-reported sensory processing issues predict lower scores on EF performance measures among autistic children (Pastor-Cerezuela et al., 2020). It is perhaps not surprising then that although EF difficulties are observed in both the home and school setting for autistic children, researchers have found evidence for a widening gap with age in actualised EF ability between autistic and neurotypical groups in the school setting, but not the home setting (Tschida & Yerys, 2022). Further, research indicates that autistic children have more variable observer-reported EF scores across home and school settings compared with neurotypical samples (Tschida & Yerys, 2022), while teachers report greater EF difficulties for children with ADHD compared with their parents (Mares et al., 2007; Soriano-Ferrer et al., 2014), indicating that neurodivergent children's EF performance is more

vulnerable to poor environmental fit, and/or that they are more likely to experience differences in the degree of environmental fit between home and school compared with neurotypical peers.

### 3 | THE CAREGIVER AS A POSSIBLE MODERATOR OF DIVERSITY IN CHILD-ENVIRONMENT ASSOCIATIONS

In the light of the above, we can consider the role of caregivers as a particularly important aspect of the child's environment, as they have the potential to moderate the dynamic interactions between the child and their environmental context (Bronfenbrenner, 1977, 2005). Several studies have illustrated that a parenting style which values child autonomy, taking the child's perspective, and providing them with choices is associated with higher child EF performance (Castelo et al., 2021; Distefano et al., 2018; Meuwissen & Carlson, 2019), while educators who foster goodness-of-fit in relationships with children by adjusting their teaching approach to match the temperament and interests of each individual child, lay the foundations for strong cognitive and social-emotional development (Driscoll & Pianta, 2010; Keogh, 1986; O'Connor et al., 2014; Vandenbroucke et al., 2018). Consistent with this, frustration induced in classroom settings has been shown to generate intra-individual differences in actualised EF sufficient to overshadow underlying differences in upper-limit EF (Pnevmatikos & Trikkaliotis, 2013), while high self-reported levels of school belonging are associated with higher working memory performance among adolescents (Wang et al., 2021).

Similarly, even where a child's window of optimum conditions does not overlap with their current environment—whether that is due to biologically-based high sensitivity to sensory inputs, poverty, societal norms, or the needs of the other individuals in the household or educational setting—a sensitive and responsive parent or teacher may be able to identify adaptations and accommodations that bring that child's experience of the environment closer to their optimum conditions: for example, by providing headphones to increase or decrease ambient noise; providing opportunities for sensory input or movement; introducing cognitive strategies and visual aids, and providing opportunities to experience other environments that may be more conducive for the individual child (Dai & Carter, 2022; McDougal et al., 2022; Russell et al., 2022). Thus, in principle, every child can perform regularly at their personal upper-limit EF ability level if they are supported to do so.

### 4 | IMPLICATIONS FOR EF MEASUREMENT

These ideas have implications for our understanding of the measurement structure of EFs, since both individual difference and measurement structure might be differently revealed in different environments. If, within a cohort of children, some have markedly different opportunities to practise a subset of EFs within an environment of good fit (for them) compared with their peers, then we may expect to find that EFs are multi-componential. In contrast, if a cohort of children all have consistent opportunities to practise each possible subset of EFs, then we might expect the data for this cohort to fit a unitary model. Although much empirical and theoretical emphasis has been placed on the measurement structure of early EF (e.g., Hendry et al., 2016; Lerner & Lonigan, 2014; Nelson et al., 2016; Scionti & Marzocchi, 2021; Wiebe et al., 2011) to date there has been far less research into the impact of variation in goodness of environmental fit on measurement structure of EF. However, there is evidence for differences in measurement structure of EF skills for autistic children (who, as previously described, are more likely to experience some common environments as sub-optimal) compared with neurotypical children (Granader et al., 2014; Tschida & Yerys, 2022).

Distinguishing between actualised EF and indicators of upper- and lower-limits of EF ability also has implications for the way in which we should design and interpret EF measures. Measuring a child's EF performance under conditions of good environmental fit, and where they are motivated to pursue a goal, is most likely to capture upper-limit

EF ability. Measuring a child's EF performance when under stress, hyper-arousal or when the child is not fully committed to the goal (because it is not motivating for them, they do not understand it, or because of competing social or attentional demands) is most likely to capture lower-limit EF ability (see also Holochwost et al. (2023) for discussion of other potential causes of lower-limit performance levels, such as nutrition, sleep, and rapport with the experimenter). A study in which adolescents were asked to complete three EF tasks each evening, and report on their affect and academic experiences during that day, has usefully elucidated the effects of fluctuations of mood and sense of belonging on EF performance such that adolescents' actualised inhibitory control and working memory performance was more likely to be at their lower-limit level on days when they reported negative mood and lower school belonging or engagement (Wang et al., 2021). A major challenge for research with participants who are too young, or otherwise unable, to reflect explicitly on their state of mind is that it is not easy to establish whether a child is likely to be operating at their upper- or lower-limit. It may be the case that lab-based studies involving very young children tend to most often capture lower-limit EF ability because toddlers are easily over-aroused in new environments and do not tend to find abstract tasks engaging. However, it may also be the case that some toddlers will perform at their upper-limits because they thrive when given close attention from an adult and external distractions are minimised. Thus, the measurement error arising from capturing some participants at their upper limit and some at their lower limit may be a particular problem when trying to capture meaningful estimates of EF in young children.

Although they tend to be written off as measurement noise, the discrepancies arising from EF measures capturing upper- versus lower-limit versus actualised EF have potential to be informative. Observer ratings, which in principle index a child's EF actualised abilities, should fall within the range of their upper- and lower-performance limits. Observer ratings which are well below that predicted by lab measures indicate that the environment (e.g., home if using parent ratings, or school if using teacher ratings) is not well-matched to the child's optimum conditions. Observer ratings which are well above that predicted by lab measures indicate that the child was performing at their lower-limit EF ability in the lab. Low agreement between parent and educator ratings could indicate that either at (pre)school or home, the child is not able to demonstrate their full ability because of a mis-match between the actual environment and their optimum environment in one of these settings. High agreement between parent and educator ratings may indicate that both environments work well for the child—although could also indicate that the child is particularly adaptable or has low intra-individual variability in their upper–lower limit range.

A major limitation to the utility of using discrepancies between observer report and lab measures in this way however has been that observer reports often target different aspects of EF than those targeted in classic EF performance tasks (Saunders et al., 2018; Toplak et al., 2013). This makes it difficult to establish whether discrepancies in lab versus observer-rated scores are due to rater bias, differences in whether actualised, lower- or upper-limit EF is being measured, or due to differences in the sub-component being measured. Recent observer-rated measures have aimed to address this by targeting behaviours that are more closely mapped to those elicited by classic EF performance tasks (Hendry & Holmboe, 2021; Nilsen et al., 2017). Others have developed group-based performance EF measures and administrative procedures which aim to embed the kinds of distractors, challenges, and competing social and behavioural options characteristic of early learning environments, in order to bring scores closer to a child's likely actualised EF level (e.g., Ahmed et al., 2021; Obradović et al., 2018).

## 5 | IMPLICATIONS FOR UNDERSTANDING EXPERIENCE-DEPENDENT DIVERSITY IN DEVELOPMENTAL TRAJECTORIES

Considering in detail the different contexts in which a child will tend to perform at their upper- and lower-limits of EF ability might yield insights into how some children develop relative strengths in some EF domains but not others: If a child only has the opportunity to engage a particular set of EF skills in sub-optimal conditions, but can practise other EF skills in optimal conditions, that child is likely to develop a 'spiky profile'. For example, 'Ava' finds the

sensory and social environment of preschool overwhelming and, although given plenty of opportunity to practise a range of EFs in the 5 days a week she spends there (e.g., through role play, circle games, etc.), she is consistently operating at her lower-limit EF ability and skill progression is slow. At home her parents have provided a calm, predictable environment that she finds less overwhelming, but do not encourage her to engage in many activities that engage her working memory or cognitive flexibility skills. Ava does however, love playing with her pet hamster and learns that if she strokes him slowly and gently he will let her play with him for longer. Over time, Ava's ability to use inhibitory control to control her movements might be expected to develop at a more rapid rate than her working memory or cognitive flexibility skills.

The way in which children interact with the world, and the way others interact with them, is influenced primarily by their *actualised* EF ability. If our fictional child Ava, despite having an interest in shapes and strong upper-limit inhibitory control skills, is so overwhelmed by her preschool environment that she is not able to make the most of those skills to get the right shapes in the right holes when playing with the shape sorter, she may start to avoid that toy and miss out on this opportunity to consolidate and extend this aspect of mathematical thinking. In other words, a child's developmental trajectory will be more influenced by what they actually do in day-to-day life than what they can do in particularly circumscribed situations. Hence, Obradović et al. (2018) have found that performance in a group-administered EF battery in an ecologically-valid classroom setting is predictive of academic achievement when controlling for prior achievement, but performance on the same battery administered individually outside of the classroom is not.

## 6 | IMPLICATIONS FOR EF INTERVENTIONS

The implication of the arguments above is that for EF interventions to be effective in influencing child outcomes, they must raise a child's *actualised* EF performance level. Raising a child's actualised EF performance level can, in principle, be achieved in one of three ways: One option is to increase the likelihood that the child is able to perform at their upper-limit level by improving the day-to-day environment for the child. Societal solutions include reducing disruptive or harmful factors such as noise pollution, and subsidising access to enriching environments such as libraries, or community play centres. Psycho-education solutions include training parents and practitioners to attune to the child and provide accommodations where needed. This approach may be particularly important for neurodivergent children (whose window of optimum conditions is less likely to overlap with the default environment), but is likely to benefit all children. For example, in a LMIC sample, exposure to a parenting intervention designed to promote responsive and sensitive parenting and engagement in developmentally-appropriate play and communication activities was predictive of EF and pre-academic skills (Yousafzai et al., 2016). In a different population, but with a parallel focus on responsive parenting, a neurodiversity-affirming parent-toddler programme aims to support EF development among toddlers with a family history of autism or ADHD by empowering parents to explore ways to help their children practise their EF skills after first establishing that their child is in a position to perform at their upper-limit EF ability because their sensory, emotional and motivational needs have been met Hendry et al. (2023). A number of preschool-based interventions have attempted to move away from decontextualised EF training (e.g., see Mattera et al. (2021), for a review). For example, in low-income preschool settings within a High Income Country, providing teachers with training in strategies designed to foster play- and peer-based learning, as well as emotionally-supporting classroom environments, has been found to improve preschoolers' preacademic skills via improvements in child EF (Raver et al., 2011).

A second option is to increase EF ability *across* the child's lower-to-upper ranges through EF training that is applicable to children's day-to-day experience, for example by embedding executive challenge into common activities and/or by teaching self-regulation and metacognitive strategies to enhance EF performance. This approach has been applied in interventions embedded in nursery and preschool settings (often alongside psychoeducation for

practitioners to improve aspects of the child's environment)—with some interventions showing evidence for small, positive effects on EF but not academic skills (Howard et al., 2020) and others showing small benefits for academic skills despite inconsistent EF benefits (Baron et al., 2017).

A third option is to use intervention to modulate children's physiological response to stress in order to weaken the effect of sub-optimal environments on EF performance and thereby increase resilience. This is the logic behind interventions involving mindfulness which have been implemented with various populations exposed to risk factors for inducing lower-limit EF performance, including economic disadvantage and civil conflict (Felter et al., 2019; Matsuba et al., 2021; Zelazo et al., 2018). Although there is much to value in psychologically-informed resilience-focused interventions, particularly in the case of intractable issues such as exposure to illness, pursuing only psychological interventions for children risks reinforcing inequity by framing these circumstances as a problem of the individual rather than society. Moreover, given that children who have been exposed to ACEs or other stressors may have strengths and abilities that have developed as an adaptive response to those stressors (Ellis et al., 2017), care should be taken to ensure that resilience-focused interventions do not undermine such strengths, and dis-empower individuals from coping with ACEs that remain unresolved.

## 7 | CONCLUDING REMARKS

We have argued that the interpretation and sensitivity of predictive models involving indicators of EF is contingent on the extent to which the EF data reflects children's actualised EF ability, versus their upper- or lower-limit EF ability. With this in mind, we recommend collecting data using a combination of measurement types (e.g., observer, performance), administrative approaches (e.g., in conditions of high and low distraction, stress and/or social demands) and contexts (e.g., home, school, lab) in order to find a more accurate proxy of actualised EF ability within these indices. Ideally, data should be collected with such measures at repeated intervals in order to use statistical modelling approaches to partition out stable, actualised EF ability from context-specific fluctuations in the ability to perform towards their upper-limit EF level (Holochwost et al., 2023). In cases where collecting multiple indices of EF across contexts and time is not feasible, we advise increasing the match between EF measures and children's actualised EF ability as much as possible by matching the data collection conditions to the circumstances in which the child's EF abilities are most commonly deployed. Furthermore, we believe that this argument extends beyond a measurement issue to implications for optimal EF intervention design: we have argued that for EF interventions to be effective in influencing distal outcomes, they must raise a child's actualised EF performance level. This can, in principle, be achieved by the provision of opportunities to practise EFs in contexts that are applicable to or embedded in their day-to-day experience, by improving the day-to-day environmental fit for the child, and by facilitating the modulation of physiological stress. To be sustainable and equitable, we argue that all three approaches are needed, and that societal-level and individually-focused solutions should be delivered in concert.

## AUTHOR CONTRIBUTIONS

**Alexandra Hendry:** Conceptualization; writing – original draft. **Gaia Scerif:** Conceptualization; writing – original draft.

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## DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

## ORCID

Alexandra Hendry  <https://orcid.org/0000-0003-1985-2521>

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