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Hypotheses and Concepts

Advantages and Limitations of a Systemic and Ecological Assessment of Executive Functions in Children and Adolescents

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Abstract

Executive functions (EFs) are high-level functions of human cognition and have been studied since the early 20th century. The evolution of theoretical models of EFs highlights the importance of taking into account all systemic influences, whether biological, environmental, or individual, when assessing these functions, particularly in children. This indicates the necessity to propose an integrative perspective for evaluating EFs. To do so, we drew on Bronfenbrenner's ecosystemic model to underline the importance of an ecological assessment. This article reviews the arguments in favor of the ecological assessment of EFs and acknowledged their limitations. The arguments came from (a) the biological level—recognizing that cerebral architecture, particularly the prefrontal cortex, which underlies EFs and its development with age encourages us to reconsider inter-individual differences, and (b) the environmental level—considering the influence of the family, educational, or even cultural system enables us to contextualize and take a step back from performance. The relationship between cold and hot executive functions was also considered. The development of ecological assessment tools, closer to the strategies and processes spontaneously implemented in everyday life, may lead to a more appropriate assessment of executive functioning, and thus to increasingly tailored support.

Keywords: child development; family; prefrontal cortex; social environment; ecological momentary assessment; executive function

1. Introduction

Traditionally, executive functions (EFs) have been defined as a set of cognitive control processes that enable behavior to be adapted to new or complex situations [1]. Since the 20th century, many authors have attempted to explain how these control functions work (e.g., [2,3,4,5]). However, those models, which were based on an adult-oriented "cognitivist" perspective, failed to consider the impact of biological and environmental factors. Recent models have attempted to shed light on both inter- and intra-individual differences by integrating all those dimensions in order to account for the multifactorial nature of EF development. Advances in developmental psychopathology and current theoretical models of EF have highlighted the significance of environmental factors and the cold and hot dimensions of EFs, thereby emphasizing the need for the development of assessment tools with a more ecological focus.

The purpose of this article was to demonstrate the importance of considering the dynamic, interactive, and multifactorial nature of EFs when evaluating them, especially in children and adolescents. Assessments of EFs that are standardized tend to reveal whether or not processes are preserved in tasks that are not part of everyday life. Nevertheless, our day-to-day activities involve EFs to a great extent. We believe it is essential to develop more ecologically oriented assessment tools. They will help us to better understand how people function on a daily basis. This article was organized as follows: (a) the manner in which EFs change and develop, as seen from the points of view of developmental science and neuroscience; (b) the value of Bronfenbrenner's ecological model for understanding how many different factors affect EFs; and (c) how ecological assessment can be used, including what it can and cannot do.

2. Executive Functions: A Dynamic and Interactive System

2.1 Three Core Executive Functions

Our discussion focuses on three core EFs: inhibitory control, working memory, and cognitive flexibility [6,7]. The term "inhibition" or "inhibitory control" refers to a variety of concepts involved in censoring activity. Inhibition is the ability to suppress a dominant or automatic response, as well as enabling emotional and motor control, directed forgetting, and resistance to interference [8]. It is a top-down regulatory mechanism that allows goal-directed behavior to disregard competing internal or external stimuli. Inhibitory control is typically divided into three interrelated subcomponents: (a) Response Inhibition corresponds to the ability to suppress a dominant or automatic motor response.

For example, the subject must not press the button when a "no-go" signal appears; (b) Cognitive Inhibition refers to the ability to suppress interfering thoughts, memories, or irrelevant information from entering or remaining in working memory. For example, the subject must ignore distracting background noise while studying; (c) Interference Control is the ability to resist competing stimuli or conflicting information. For example, the subject must name the ink color (not the word) in a Stroop task.

The ability to store and manipulate temporary information in memory is known as working memory. Some authors have also used the term "updating" to describe this function. It plays an essential role in maintaining the goal in memory during a task [4,9,10]. It involves active processing and transformation of information. Different subsystems are classically described [2]: (a) Central Executive, which is a supervisory system responsible for attention control and coordination; (b) Phonological Loop, which maintains verbal and auditory information; (c) Visuospatial Sketchpad, which maintains visual and spatial information; and (d) Episodic Buffer, which integrates information across domains and links working memory to long-term memory.

Mental flexibility, cognitive flexibility, attentional flexibility, switching, shifting, task switching, set shifting, or attention shifting refer to flexible mechanisms for moving from one state to another [11]. Many mechanisms are involved [12,13]: (a) Set shifting refers to the ability to switch from one activity to another and to change and alternate between different angles of view; (b) Perspective taking refers to considering alternative viewpoints or interpretations; (c) Strategy shifting refers to the ability to abort ineffective approaches and adopt new ones; and (d) Conceptual reframing which allows for the reinterpretation of situations in new ways.

These components allow adaptive modification of cognition and behavior when previously effective strategies are no longer appropriate. Miyake et al. [4] emphasized that these three EFs are both distinct and correlated, sharing a common foundation of cognitive control. Maintaining and updating relevant information is ensured by working memory, which is a necessary condition for the inhibition of automatic or dominant responses [14]. On the other hand, inhibition helps block out irrelevant information, which in turn helps improve the efficiency of working memory. The ability to switch between different strategies or rules in working memory is known as cognitive flexibility [1]. More specifically, it has been confirmed by recent reviews and meta-analyses that EFs should be understood as a dynamic system based on the interaction between inhibitory control, working memory, and cognitive flexibility at all ages [15,16]. Cognitive flexibility is largely predicted by working memory and inhibitory control. It involves the simultaneous updating of relevant rules and the inhibition of responses that have become inadequate [17].

2.2 Cold vs Hot EFs

EFs can be classified into "cold" and "hot" components. Cold EFs are logical, cognitive, and emotionally neutral processes used in problem-solving and goal-directed behavior. They contribute to rational and analytic thinking, abstract reasoning, and logical decision-making. Hot EFs refer to goal-directed cognitive processes in the presence of motivational, affective or reward-related stimuli. They contribute to emotionally driven processing, reward and punishment sensitivity, social decision-making, and impulse regulation in emotional contexts [18].

The three core EFs are involved in cold and hot processing. In regard to inhibition, the suppression of automatic or dominant responses in neutral, rule-based contexts refers to the cold component of inhibitory control [18]. The suppression of impulses in emotionally arousing or reward-driven contexts relies on the hot component of inhibitory control [18]. The hot component is involved in delayed gratification tasks and the control of anger in conflict situations [18]. For working memory, the cold component refers to the maintenance and manipulation of neutral, abstract information. The cold component is involved in mental arithmetic, remembering a phone number, or following multi-step instructions [18]. Maintenance and manipulation of emotionally or motivationally salient information refers to the hot component [18]. For example, it is involved in keeping in mind social feedback, holding emotional goals during conflict, or weighing reward values during decision-making. Concerning cognitive flexibility, the cold component refers to shifting between rules, strategies, or mental sets in abstract contexts [18]. It is involved in task-switching paradigms and switching between mathematical operations. The shifting of perspectives or strategies in emotionally charged or socially meaningful contexts relies on the hot component. It is involved in reframing criticism constructively, adjusting strategy after social rejection (Table 1).

2.3 Neural Basis and Neurodevelopment

Cold EFs are more dependent on the activation of the lateral prefrontal cortex (LPFC), including the dorsolateral prefrontal cortex (DLPFC) and ventrolateral prefrontal cortex (VLPFC). In contrast, hot EFs involve more ventral regions of the prefrontal cortex, such as the orbitofrontal cortex and the ventromedial prefrontal cortex [15,16,17,18,19]. Neuroimaging and non-invasive brain stimulation studies proposed a prefrontal-cingulate network model in relation to cold and hot EFs. The model suggested the following: (a) The lateral prefrontal cortex and associated regions (such as the DLPFC, VLPFC, and inferior frontal gyrus) are more closely related to the dorsal anterior cingulate cortex. Together, these regions are more involved in cold EFs; (b) The medial and orbital prefrontal regions are more linked to the ventral anterior cingulate cortex and

Table 1. Summary of the hot and cold components of executive functions.

Executive functions	Cold processing	Examples	Hot processing	Examples
Inhibition	Suppression of automatic or dominant responses in neutral, rule-based contexts	Stroop task, Go/No Go task, or ignoring distractions during studying	Suppression of impulses in emotionally arousing or reward-driven contexts	Marshmallow task delayed gratification tasks, control anger in a conflict situation
Working memory	Maintenance and manipulation of neutral, abstract information	Mental arithmetic, remembering a phone number, and following multi-step instructions	Maintenance and manipulation of emotionally or motivationally salient information	Keeping in mind social feedback, holding emotional goals during conflict, or weighing reward values during decision-making
Cognitive flexibility	Shifting between rules, strategies, or mental sets in abstract contexts	Task-switching paradigms, the Wisconsin Card Sorting Test, and switching between mathematical operations	Shifting perspectives or strategies in emotionally charged or socially meaningful contexts	Reframing criticism constructively, adjusting strategy after social rejection

the posterior part of the cingulate cortex. These regions are more relevant for hot EFs [20]. Furthermore, the emotional and motivational processing that occurs in subcortical regions, such as the amygdala and insula, is connected to this active EF stream [21].

Although the same brain areas are involved in many EFs, there are still specific brain characteristics that can explain the fact that many studies have reported minimal or no correlation between hot and cold EF measures [22], suggesting that the relationship between the two is not strong. That suggested that different cognitive domains are indexed and that those measures need to be evaluated separately. Indeed, cold inhibition is also associated with the anterior cingulate cortex, cold working memory is linked to parietal cortex, and cold cognitive flexibility is linked to frontoparietal cortex. Hot inhibition and cognitive flexibility are related to limbic system interactions, and hot working memory is linked to amygdala prefrontal connectivity. Fig. 1 (Ref. [20]) provides an overview of the brain structures associated with cold and hot EFs.

Children mobilize the same cognitive processes in all situations requiring control [23], so the processes are not very dissociated. In older children, however, a more selective alteration of certain functions can be observed [1]. Around the age of 6–7, the processes become more specialized, evolving into components that function more autonomously [4,24]. These developmental changes are based on brain maturation, indicating that prefrontal cortex (PFC) activity appears to be diffuse in children and tends to develop toward focal activity [25]. The PFC has a very long maturation period, from early childhood to early adulthood. The maturation of EFs would then follow the maturation rhythms of the brain, making the fronto-subcortical circuits more vulnerable [26]. Although inhibition and working memory improve continuously from childhood onward, they become more specialized and coordinated with cognitive flexibility during adolescence, alongside the structural and functional reorganization of the PFC [16]. There may be two sensitive periods of high plasticity in the PFC when the environment plays an influential role: early childhood and adolescence [27]. In adolescence, puberty, marked by the secretion of gonadal hormones with the reactivation of the hypothalamic-pituitary-gonadal axis, leads to numerous cerebral reorganizations, particularly in the frontal cortical regions, resulting in behavioral changes [25]. The secretion of gonadal hormones during puberty could therefore be linked to the development of the medial PFC [25]. So, adolescence is a critical period for the functional integration of executive processes that are linked to the gradual maturation of fronto-parietal brain networks. Inhibitory control mainly develops during childhood, reaching full maturity at around 12 years of age [28]. Best and Miller [29] suggested that the critical developmental periods for cognitive flexibility and working memory are around the ages of 8–10 and 4–15 years, respectively. Few studies have examined how hot EFs develop. Nevertheless, research has indicated that the motivational domain of EFs develops later during adolescence [30,31]. The developmental trajectory of cold and hot EFs may be similar during childhood and start to differ during adolescence. Hot EFs show somewhat nonlinear changes, whereas cold EFs exhibit linear changes [32].

During adolescence, these structures and their connections undergo increased myelination and synaptic remodeling, enhancing the efficiency of information processing and the ability to simultaneously integrate inhibition, working memory, and cognitive flexibility [33]. The effectiveness of cognitive flexibility depends on the coordination of frontal networks that support goal maintenance, interference suppression, and behavioral adjustment [33]. Sadozai et al. [15] suggested that cognitive flexibility at this age relies heavily on the capacity to actively maintain goals in working memory while suppressing irrelevant responses or rules. This process is supported by prefrontal circuits, which are still developing [15]. The interindividual variability observed in cognitive flexibility performance during

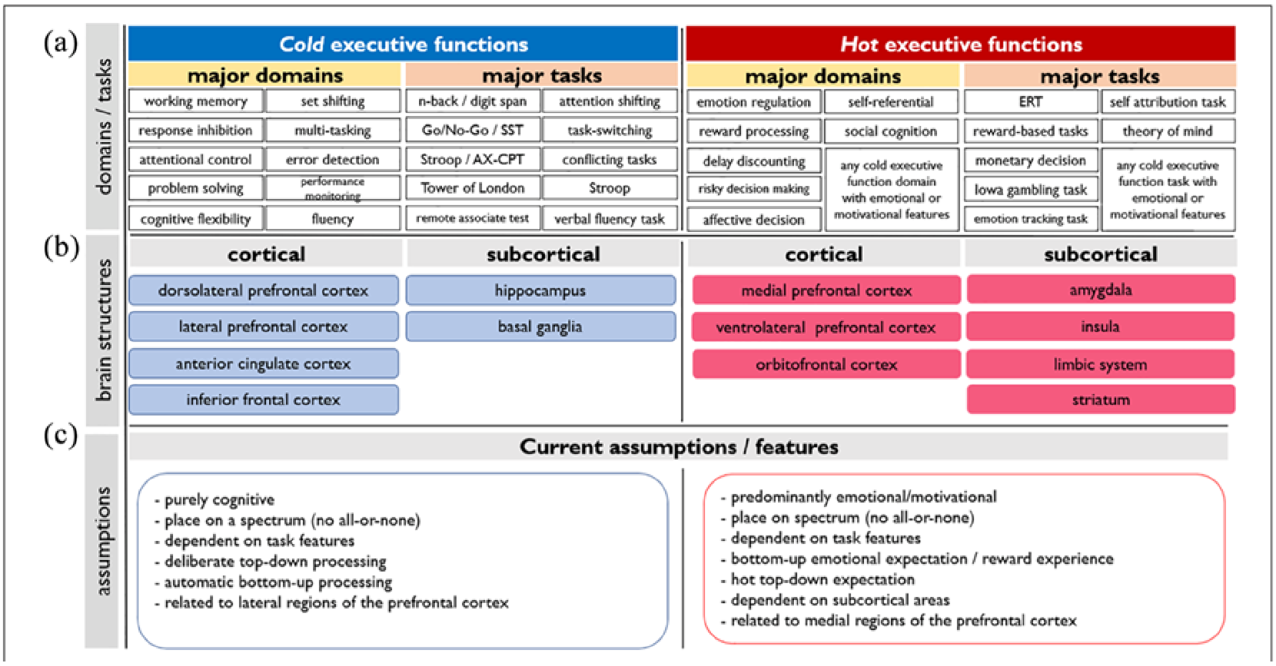

Fig. 1. Neural correlates of hot and cold executive functions [20]. (a) provides an overview of the main processes and the key tasks involved in assessing them. (b) describes the brain structures involved, and (c) outlines the main hypotheses regarding their functioning. SST, Stop-Signal Task; AX-CPT, AX Continuous Performance Test; ERT, Emotion Regulation Task.

adolescence may be explained by this immaturity, as well as increased sensitivity to interference and contextual changes [17].

These neuroanatomical changes partly explain the interindividual variability observed in executive performance during adolescence and adolescents' sensitivity to interference, distractions, and complex contextual changes. It therefore appears that each component of EF seems to have its own developmental trajectory and depends on the development of lower-level systems [8,27,34].

2.4 A Recent Developmental Model of EFs: Frick and Chevalier (2023)

The recent model proposed by Frick and Chevalier [35] used the term "cognitive control" to refer to EFs. The model is based on the idea that as children develop, they move from being controlled by external factors to being self-directed. This movement is seen as a continuous process, with the two stages being interconnected. External control constitutes a form of externally directed control, providing the individual with explicit instructions concerning the objective to be pursued, the pertinent information to be taken into account, the actions to be performed, etc. Conversely, self-directed control refers to autonomous control directed by the individual. The authors make a distinction between the various types of processes involved in cognitive control. Goals are the starting point for cognitive control, so first we need to identify them. The identification of goals is linked to external control and is based on the knowledge that has been built up in self-directed control. This accumulated knowledge includes reflection, abstract representations, knowledge, beliefs, and values [36]. Thus, greater efficiency in goal identification influences the development of cognitive control.

However, this ability is dependent on the capacity to track past and future contextual cues, a process referred to as "context-tracking" by the authors [35]. The authors argued, "that self-directed goal identification requires keeping track of contextual information, which we refer to as context tracking (i.e., monitoring, activating, and maintaining)" [35] (p. 195). So, context-tracking enables us to memorize and situate ourselves in the hierarchy of goals and sub-goals, based on past experience and future projections [35]. This process requires the use of long-term and prospective memory, as well as working memory [35]. Furthermore, the authors mentioned that "Individuals must also use this contextual information to determine when and what behavior and how this behavior should be engaged to achieve sub-goals and goals, which we refer to as the ability to select goals or goal selection" [35] (p. 195). "Goal selection" enables goals and sub-goals to be achieved based on contextual clues, i.e., what to do (refers to "the task goal activation process") and how to do it (refers to "the task rule activation") [35] (p. 195). The selection of goals and the tracking of context are influenced by each other [35]. Finally, "goal execution" requires the mobilization of EFs and can influence contextual cues, leading to a revision of goal identification [35]. That model emphasized the influence of the subject's representations and experi-

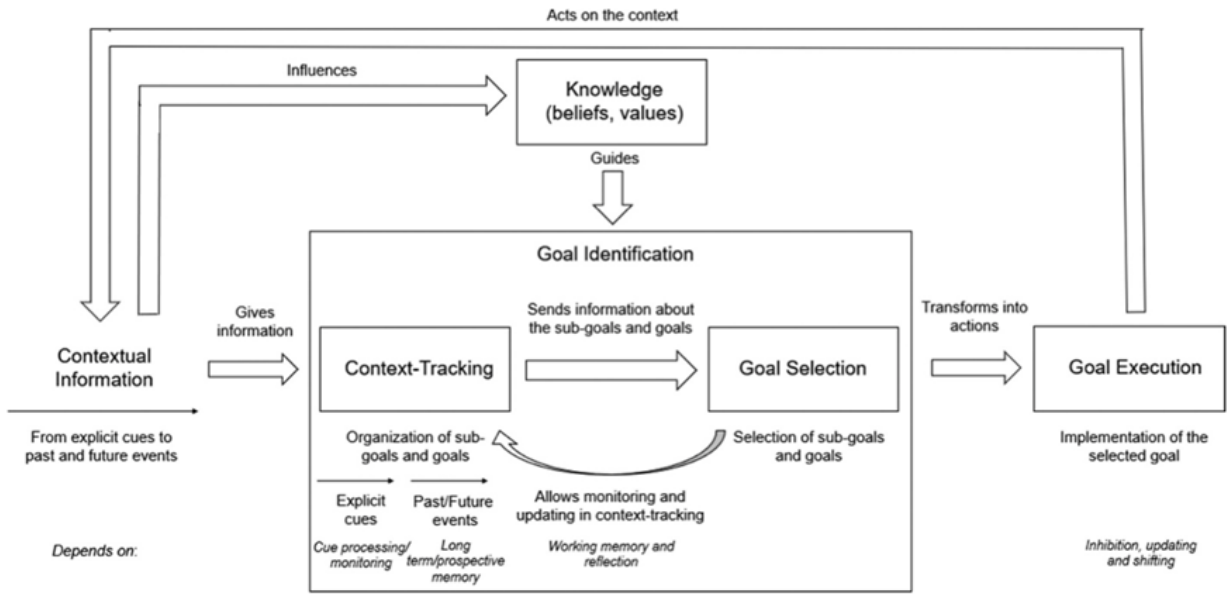

Fig. 2. Frick and Chevalier's (2023) model of self-directed cognitive control development [35]. The arrows illustrate how the model works, as described above.

ences on the context-dependent mobilization of EFs. The way in which external control is assessed involves the use of performance-based tests, which explicitly guide the subject. In contrast, self-directed control is assessed using questionnaires and ecological tools, which allow more freedom in the implementation of strategies. Fig. 2 (Ref. [35]) illustrates the model proposed by Frick and Chevalier in 2023.

Recent models, therefore, highlighted the importance of considering internal and external factors that affect children, such as the impact of context, knowledge, beliefs, and values on their performance on tests. Environmental factors must also be considered, in addition to the neuroscientific factors mentioned. It is in this context that we believe it is relevant to consider holistic developmental models, which can help us to understand how individuals and communities can be supported to achieve positive developmental outcomes.

3. Bronfenbrenner's Biopsychosocial Model and Ecological Assessment

3.1 Bronfenbrenner's Model

Current thinking in psychology is that human development is the result of complex interactions between factors that are part of a person's biology from birth and many different factors in their environment, including society and culture. The biopsychosocial model proposed by Bronfenbrenner was a relevant theoretical framework for understanding the complexity of development from this integrative perspective [37,38]. This ecological model presented a holistic and systemic view of development. Human development is the product of reciprocal and increasingly complex interactions between different close and distant environments. These are referred to as systems [37]. The Bronfenbrenner model looked at the mechanisms involved in development and showed how "proximal" processes, which play a central role and have a direct impact on child development, and other, more peripheral processes that have more diffuse areas of influence, work together. That transactional model is about reciprocity. The environments in which children grow up have a huge impact on their development, but children also change the systems they interact with. As shown in Fig. 3 (Ref. [39]), different systems are described in the model; they are interdependent and nested within each other.

Bronfenbrenner's model is relevant for enabling a multi-level analysis of the various factors involved in cognitive development, particularly the multifactorial dimension of EFs, because it distinguishes the role of different systems according to their area of influence on child development. Some of these systems are more immediate, such as family or school, and others are more distant. This integrative developmental view is now an essential approach for contemporary research seeking to understand the complexity of the proximal and distal processes involved in cognitive development and the dynamics and variability of developmental trajectories [40,41]. According to Bronfenbrenner's model, the development of EFs can be understood as the result of complex interactions between a child's personal characteristics (both innate and acquired) and the various environmental contexts they are exposed to.

Ontosystem - Many individual factors are involved in the development of EFs. The child's age is one of the first factors described, in connection with the gradual maturation of the prefrontal cortex [40,41].

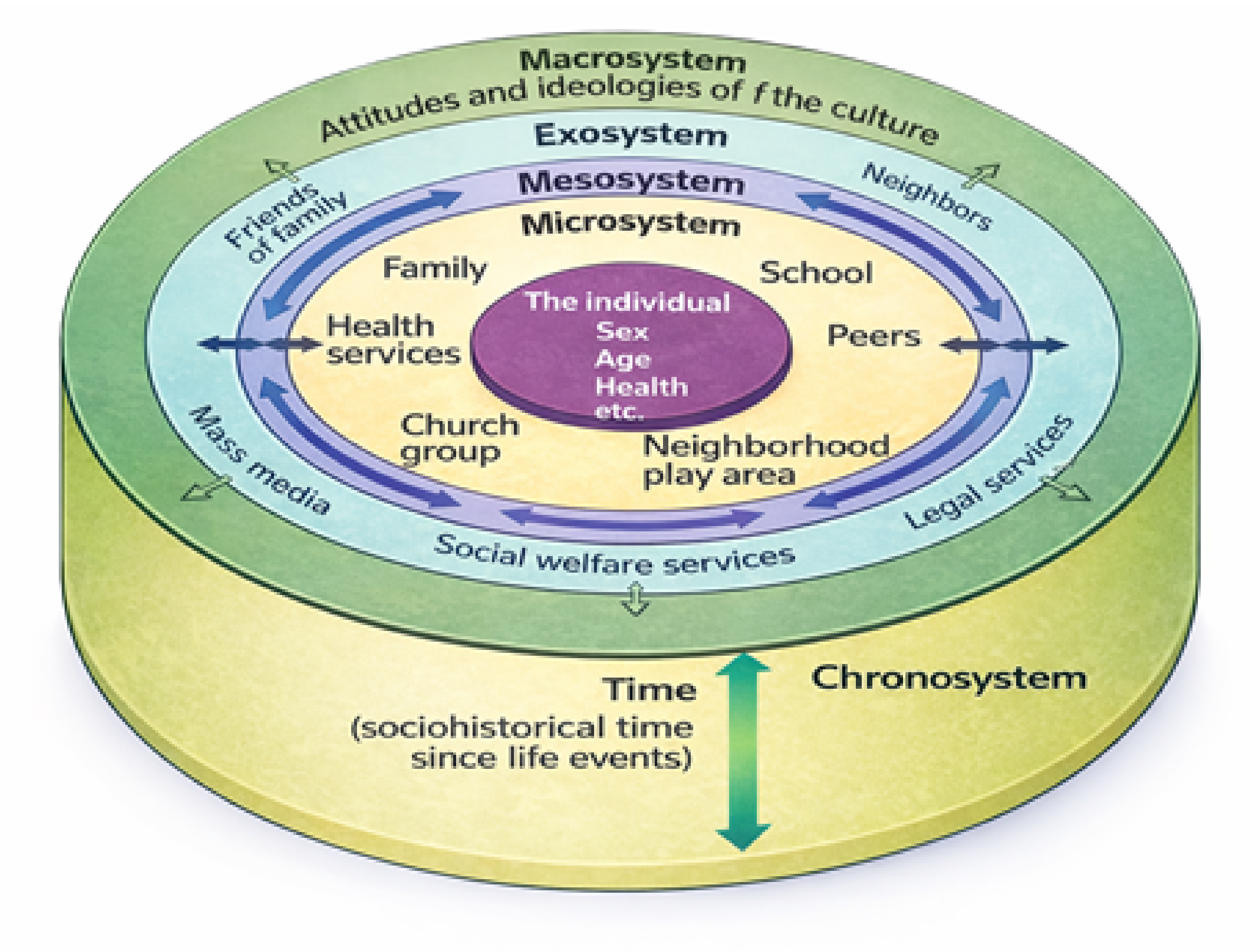

Fig. 3. Diagram of Bronfenbrenner's model [39]. The ontosystem is the inherent characteristics of the individual (innate or acquired predispositions, such as sex, age or health), their biological (genetic and physical) and psychological (affective, cognitive, and behavioral) characteristics. Microsystem: the immediate environments in which the child develops (family, daycare, school). Mesosystem: the possible interconnections between different microsystems, for example, the relationship between the family and the school. Exosystem and the macrosystem: more distal systems that do not directly involve the child but can, however, modify their immediate environments (particularly the family system, school, socioeconomic contexts, or public policies proposed in the fields of economics, health, or education) and thus influence their development. Chronosystem: the importance of taking temporality into account in development. Each of the systems described in the model evolves over time. These constant changes require constant adjustments in the interactions between the child and their different environments. The arrows in the figure highlight the influence that each system has on the other systems.

Biological sex is also an influential factor, with preschool girls performing better on all EFs than did boys of the same age [23,42,43]. The child's temperament is another innate individual characteristic that modulates adjustments to environmental stimuli. Temperament incorporates behavioral and cognitive dimensions such as executive control, which form the basis of self-regulation [44,45,46]. Temperament plays a major role in cognitive development, particularly in terms of EFs [47,48]. For example, research has shown links between temperament, activation of the dorsolateral prefrontal cortex, and cognitive flexibility in children aged 4 to 5 [49], and links between temperament and working-memory performance in preschool children [50].

In line with a contemporary integrative approach, some recent literature has focused on the complexity of the relationships between genetic and environmental factors involved in the early development of EFs, which explains the variability in developmental trajectories observed during childhood and adolescence [47,48]. Studies have suggested that certain aspects of EF are shaped by biological factors shared with other cognitive skills, and remain sensitive to environmental influences. In this area, Friedman et al. [51] showed that 29% to 56% of the variance in executive-task performance can be attributed to hereditary factors, suggesting a moderate but significant biological basis for these skills. The intrauterine environment and prenatal biological factors have a lasting influence on executive development [52,53,54]. Anxiety, depression, substance exposure, and socioeconomic stresses of the mother during pregnancy can affect the developing brain through fetal programming mechanisms, including via maternal inflammation, cortisol production, and alteration of the hypothalamic-pituitary axis [52,53,54]. Maternal stress, mood, substance use, and socioeconomic adversity of the mother during pregnancyhave been associated with more difficult trajectories of EFs in children aged 3 to 5 years, with poorer performance in the areas of inhibition and working memory [55]. Although neurobiological maturation provides a foundation for the development of EFs (as discussed in the previous section), it is the influence of other systems involving the broader social environment, interactional experiences, and particularly the quality of parenting practices that largely modulate their expression, consolidation, and developmental trajectory. For example, maternal mood disorders can affect the postnatal development of the child's EFs, particularly through parenting practices and the quality of parent-child interactions [54].

Microsystem - The microsystem plays a major role in cognitive development, particularly in the development of EFs. Among the known factors acting as proximal processes, the role of the family environment, particularly the quality of parent-child interactions and appropriate parenting practices, is often mentioned [1,56,57,58,59,60]. Research has shown that parenting behaviors that support autonomy and emotional regulation promote better development of EFs in preschoolers [61,62]. For example, recent research by Wei et al. [63] highlighted the link between displays of maternal support and warmth and children's performance in planning and working memory; those authors also mentioned the need to consider the effect of paternal parenting. Family environments that encourage frequent conversation, structured play, and routines (guided and stimulating) are also conducive to the healthy development of EFs [64], particularly in the development of attention and inhibitory control. However, some results are sometimes difficult to interpret, which encourages the development of new methods for the assessment of EFs in children ([65], for review). The meta-analysis by Valcan et al. [66] in 2017 confirmed the complexity of the links between parental behaviors and the development of EFs. Thus, positive parental behaviors (warmth, responsiveness, sensitivity) are associated with better performance in all dimensions of EFs (inhibition, shifting, working memory). Negative parental behaviors (control, intrusiveness, detachment) are associated with an overall decline in EF performance and a decline in inhibitory performance. Finally, cognitive parental behaviors (autonomy support, scaffolding, cognitive stimulation) are associated with increased performance in all dimensions of EFs, with a pronounced effect of age (greater in younger children). School is another microsystem that influences the development of EFs. More specifically, activities offered to preschoolers support the development of EFs [67,68]. As an example, recent research by Dolgikh et al. [69] highlighted the impact of implementing a system of additional teaching offered for one year to children aged 5 to 6 on their working-memory performance. The psychosocial model also focuses on the fact that the effects of certain factors on the development of EFs are not unambiguous and can, in turn, be moderated by the influence of other factors. For example, the influence of parenting practices is strongly modulated by the presence of other factors (mediators and moderators), particularly those related to the mental health of parents [70,71].

Mesosystem - Recent research has shown that the interconnection of microsystems (the mesosystem) greatly influenced the development of EFs. Therefore, the relationships between parents and their environments (especially the school) should be prioritized in order to optimize the development of EFs [72,73,74]. Good communication between parents and teachers and consistency in educational and parental messages strengthen EFs by providing consistent, structured, and complementary learning structures [75].

Exosystem and macrosystem - These systems can influence the development of EFs more indirectly by acting on the child's immediate environments. For example, the study by Campos-Gil et al. [76] showed that the quality of the environment in which the child grows up (such as the quality of the family's housing) is associated with the development of certain executive skills, such as decision-making and planning. In addition, differences in socioeconomic status are also associated with differences in the development of executive skills [77,78]. Families with high socioeconomic status often have appropriate parenting practices with access to richer educational resources, which are associated with better EF performance in children, especially for working memory and inhibition [79]. At the macrosystem level, cultural differences in educational practices and social expectations also modulate how EFs develops. Cross-cultural studies on the development of EFs in children have indicated that identical factors can optimize or limit development, but that there is also variability related to environmental influences in the development of all EFs [80,81,82,83].

Chronosystem - The temporal dimension of Bronfenbrenner's model highlights the need to take the developmental dimension into account when studying EFs and specifies how they develop dynamically in systems that are themselves constantly changing over time, depending on sensitive periods, events that constitute periods of transition and change in the child's life, and the systems surrounding them [38].

As we have seen, the development of EFs depends heavily on contextual factors. This suggests that an ecological assessment of EFs is necessary.

3.2 Application of Bronfenbrenner's Model to Assess EFs

Holochwost et al. [84] applied Bronfenbrenner's ecological model to assess EFs in children, identifying factors that influence individual variability. They identified three main levels: (a) at the intra-individual level, the authors mentioned reaction time, linked to perseveration and motivation, as well as the activity of neurophysiological systems, such as the hypothalamic-pituitary-adrenal axis, which can be influenced by the time of day; (b) at the level linked to the immediate context of the test environment, we find the nature of the task, such as the hot or cold nature of the processes assessed, the length of the task, as well as the relationship with the examiner, notably the commonalities or differences with the latter, influencing the mobilization of the child's EFs; and (c) for the level of the child's microsystem, we find nutritional factors, notably glucose levels, as well as sleep duration and quality. All of these factors (at the very least) are likely to influence the mobilization of the child's abilities and may therefore shade the interpretation of his results. These factors are at the root of intra-individual differences in children's executive performance and influence their state-type EFs.

Holochwost et al. [84] also distinguished state-like EFs that correspond to abilities observed in a particular temporality and context, and trait-like EFs that correspond to the ability to mobilize one's EFs across time and contexts. This proposal by the authors allows us to understand and explain the weak correlations between performance-based tools and ecological questionnaires and tools. The performance observed in a test situation, the state-like EFs, would be no more than a representation of the child's executive abilities in a given situation. In order to capture children's true executive abilities, or trait-like EFs, the authors suggested averaging the child's performances observed at different times [84]. This method is used in the Ecological Momentary Assessment (EMA), which will be discussed in more detail in section 4.2.2.

Indeed, subjects' performance on EF measures cannot be considered in isolation from the purposes and contexts in which they are used and the mental content they activate [36]. The latter supports the necessary influence of elements of the subject's ontosystem, such as knowledge, values, beliefs, preferences, and interests, in the mobilization and level of engagement in EF tasks. In addition, the content of assessments, as well as the degree of familiarity felt by the child, greatly influences their mobilization [85]. Previous experience, the significance of the tasks, and the materials they consist of have a strong impact on the mobilization of the child's EFs in the test situation. For this reason, it is more accurate to say that the performance observed in any type of assessment only gives an estimate of the potential efficiency of children's EFs at a given moment in their development, and therefore of their state-like EFs [84]. The model developed by Holochwost and colleagues [84] invited us to move away from a linear vision of EF assessment toward a much broader understanding of the environmental, biological, and individual determinants of children's executive performance.

Fig. 4 shows our proposed synthesis of EF development according to an ecosystemic approach, taking into account biological and environmental factors.

4. Distinguishing Existing Assessment Methods

Initially, it was generally agreed that assessing EFs prior to adolescence was irrelevant, given the developmental immaturity of the frontal lobes. The measures used with children were primarily adaptations of tests originally created for adults [86,87,88]. Instructions, rules, and stimuli can be complex and unappealing, as can response modalities, failing to distinguish between age, complexity, and EF impairment [89]. Therefore, discussions surrounding the assessment of EFs in children were lagging behind. Broadly speaking, there are two types of tools for assessing EFs: standardized and ecological.

4.1 Standardized Assessment

Performance-based tests represent the vast majority of assessment tools used to measure EFs. They help to understand how an individual functions, using highly standardized procedures to update response accuracy or response time, or both [90]. Nevertheless, these tools involve exposing the subjects to unnatural situations that are new or complex [91], without taking into account the systems in which the subjects develop [37]. We have seen the extent to which the environment influences EFs. Performance-based tests allow us to understand EFs in a given laboratory situation, i.e., state-type EFs, for diagnostic purposes. Undoubtedly, what is new to one may not be new to another [87]. Two equivalent scores from one child to another do not have the same meaning, depending on the child's degree of previous expertise in the proposed activity (ontosystem). So, the subjectivity of the novelty criterion limits impartial standardized exploration of EFs. The structured nature of this testing environment may therefore be the cause of overestimating the subject's performance and the underestimation of his functional difficulties; the administrator acts as the child's executive control [92]. This environment leaves little room for the mechanisms of initiation, prioritization, and compensatory strategies that the child may mobilize in real life as the situation forces the child to use a particular strategy [87,88]. Due to this assessment context and the use of neutral materials that do little to engage patients' affective and motivational processes, performance-based tests are rarely able to capture the hot components of EFs [93]. Despite the fact that these measures are generally far removed from subjects' daily lives, they nevertheless provide information about how a structured environment promotes and improves performance [90]. These tools make it possible to place the subject within a norm, in a quantitative way, but with-

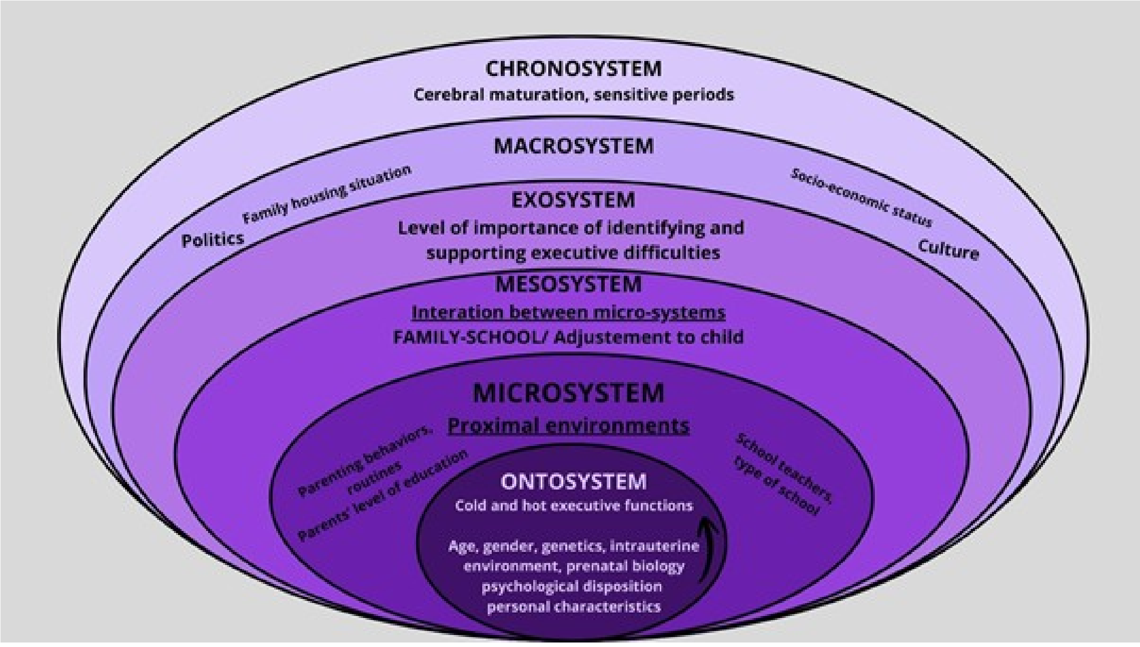

Fig. 4. Application of Bronfenbrenner's biopsychosocial model to EFs. The arrow in the "ontosystem" section indicates that each system influences the others. EFs, executive functions.

out explaining the processes engaged to obtain these results. Analysis, perspective, and hypotheses vary from one clinician to another.

It is certain that standardized tools offer a number of advantages, such as using the hypothetico-deductive approach, making the success criteria explicit, reducing measurement error, and requiring only a short duration, unlike ecological tools [87]. Chaytor et al. [94] concluded in their study that neuropsychological tests account for only 18%–20% of the variance in everyday abilities. Indeed, ecological assessments correspond more to situations personally experienced by the subject in their daily life, enabling a direct assessment of the mobilization of skills in daily activities.

The ecological validity of performance-based tests is thus not always satisfactory, resulting in a large discrepancy between what is measured and the behavior manifested in everyday life [88,90]. All these arguments support the need to rethink EFs assessment tools, favoring the spontaneous, dynamic mobilization of children's abilities as they would unfold in their natural environment.

4.2 Ecological Tools

We consider ecological assessment to be any type of tool that attempts to understand an individual's functioning based on daily-life situations, in order to predict their future behaviors in everyday life [35]. This can refer to observation of the child in a natural situation, performance-sampling methods, or even questionnaires, making it easier to understand trait-type EFs. Ecological assessments allow for the capture of spontaneous and non-maximized performance. Many authors have sought to develop ecological tests in these contexts. Table 2 (Ref. [91,95,96,97,98,99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,114,115,116,117,118,119,120,121,122,123,124,125,126,127,128]) contains a broad overview of existing tools. Indeed, ecological assessments are often time-consuming, and the scoring criteria are more subjective, which can lead to different results depending on the examiner [90]. We can see that most of these tools concern adult populations. A real lack exists of tools for children and adolescents, despite the fact that there is a genuine clinical issue given the increase in neurodevelopmental disorders.

4.2.1 Questionnaires

Questionnaires or rating scales have been developed to identify more precisely the functional consequences of dysexecutive functioning in everyday life. They may be intended for the subject and/or their family, and subjectively assess behaviors based on a list. They allow us to investigate everyday functioning over a longer period of time (the last 6 months, for example) than do performance-based tests, since the items refer to frequent behaviors. Moreover, since the questionnaires are administered in a structured, novel, quiet, one-on-one testing environment, standard tests of executive functioning do not always reveal executive deficits during administration. We therefore consider questionnaires to be ecological assessment tools in terms of both their content (items) and their methodology (questioning the subject themselves or someone who spends time with them on a daily basis and has a certain expertise in how they function).

Table 2. Summary of EF ecological measures.

Name of test	Author(s)	Population	Brief description
Behavioural Assessment of the Dysexecutive Syndrome (BADS)	Wilson et al. (1996) [95]	16–87 years	
Children's version: BADS-C	Emslie et al. (2003) [96]		
Birthday Task Assessment	Cook et al. (2008) [97]	8–16 years	Subjects are asked to prepare a birthday party. They are asked to wrap two presents, prepare a card and make two peanut butter and jelly sandwiches.
Executive Function Route-Finding Test (EFRT)	Boyd & Sautter (1993) [98]	Adults with brain injury	Subjects are asked to find a certain room in an unknown building of several floors as quickly as possible. The examiner accompanies them, is there to answer questions, to encourage and can potentially ask some questions to find out about the subjects' search strategies.
Kitchen Task Assessment (KTA)	Baum & Edwards (1993) [91]	53–85 years	Subjects are invited to create a chocolate cake recipe. They are provided with all the objects and ingredients needed to make the cake, as well as distracting elements.
Cooking Task (EF2E)	Chevignard et al. (2000, 2008) [99,100]	23–60 years	
		17–63 years	
	Poncet et al. (2015) [101]	15–68 years	
Children's Cooking Task (CCT)	Chevignard et al. (2009, 2010) [102,103]	8–14 years	
		8–20 years	
Preschool Kitchen Task Assessment (PKTA)	Fry et al. (2015) [104]	3–6 years	
Children's Kitchen Task Assessment (CKTA)	Rocke et al. (2008) [105]	8–12 years	
	Berg et al. (2012) [106]		
Multiple Errands Test (MET)	Shallice & Burgess (1991) [107]	Adults	Individual or group practice
Revised version: MET-R	Morrison et al. (2013) [108]	Adults	Subjects are asked to plan various activities using a map. They are asked to run errands in a city. They are instructed to make purchases as quickly as possible, spending as little money as possible and not entering shops unnecessarily. Temporary constraints are also imposed.
Hospital version: MET-HV	Knight et al. (2002) [109]	Adults	
Simplified version: MET-SV	Alderman et al. (2003) [110]	18–59 years	
Computerized version: VMET	Rand et al. (2009) [111]	Adults and seniors	
BMET	Dawson et al. (2009) [112]	Adults	The test can be carried out in a real-life situation, on a computer or in paper-and-pencil format. In paper-and-pencil format, the task is to plan the order of tasks in 15 minutes.
Present in the "Groupe de Réflexion sur l'Evaluation des Fonctions Exécutives" (GREFEX battery)	Roussel & Godefroy (2008) [113]	From <40 years to >60 years	
Party test	Chalmers & Lawrence (1993) [114]	Adolescents, adults and seniors	Subjects are asked to plan an unexpected party for a teenager at their home. They have 19 tasks to complete and three assistants for whom they can assign different activities.
Photocopy Tasks	Crépeau et al. (1997) [115]	Adults with traumatic brain injury (20–41 years)	Subjects are immersed in a work environment and given 16 photocopier-related tasks to complete. These 16 tasks are comprised of four types of complex tasks: analysis tasks, solution tasks, planning tasks and control tasks.
Six Elements Test (SET)	Shallice & Burgess (1991) [107]	Adults	Subjects are asked to complete three types of activity, each comprising two parts, in 15 minutes. Subjects must organize their time and respect certain rules. It is not possible to combine the two parts of the same test. The first parts of each test earn more points than the second parts.
	Garnier et al. (1998) [116]	From age 18	
Modified version: The Hotel Task	Manly et al. (2002) [117]	Adult brain injury	
Present in the BADS battery	Wilson et al. (1996) [95]	From 16 to 87 years old	
Present in the GREFEX battery	Roussel & Godefroy (2008) [113]	From <40 years to >60 years	

Table 2. Continued.

Name of test	Author(s)	Population	Brief description
The Executive Secretarial Task (EST)	Spikman et al. (2010) [118]	Adults	This test consists of organizing and prioritizing various tasks over an extended period of 3 hours. Subjects are alone in a room containing a box with various tasks and objects inside: a phone book, a calculator, a telephone, office supplies, a list of company rules, a diary and an office plan. They are instructed to complete all these tasks, bearing in mind that some have a time limit and that an urgent task comes up during the assessment.
The Jansari Assessment of Executive Functions (JEF)	Jansari et al. (2014) [119]	Adults with traumatic brain injury	Using non-immersive virtual reality, subjects are immersed in an office and confronted with tasks with ambiguous and multiple solutions. Their task is to organize a meeting.
	Denmark et al. (2019) [120]	Adults with focal frontal lobe lesions (25–69 years)	In the child version, subjects are invited to organize their own birthday party. They have a house with a kitchen, living room, playroom, entrance and garden. They are confronted with real-life situations and dilemmas involving various solutions. They listen to the script and receive an instruction card, lists and cards of friends to invite. The test begins when the child finishes reading the letter from his parents, giving instructions for the party and draws up a to-do list.
Children's version: JEF-C	Jansari et al. (2012) [121]	10–18 years	
	Gilboa et al. (2019) [122]	10–18 years	
	Orkin Simon et al. (2022) [123]	11–18 years	
Virtual Action Planning-Supermarket (VAP-S)	Marié et al. (2003) [124]	Adults and seniors	Subjects are digitally immersed in a supermarket and instructed to make seven purchases. They are asked to make as few detours as possible, to pay before leaving and to find items hidden among distractors.
	Klinger et al. (2004) [125]	Adults and seniors	
	Klinger (2006) [126]	People aged 80 and over with Parkinson's disease	
Virtual Library Task (VLT)	Renison et al. (2008) [127]	Adults with traumatic brain injury	In this role-playing task, subjects are given various missions to carry out related to the running of a library, in a non-immersive environment.
Virtual Planning Test (VIP)	Miotto & Morris (1998) [128]	Adults with traumatic brain injury	Subjects have to plan activities for a four-day trip, from the day before to the day after, in the form of a board game. They must then carry out the activities and plan for the following day. Once the day is over, there is no going back. The proposed activities are varied and include distracting activities. Another version of the task is possible, referring to preparing a few days before the trip.

VMET, Virtual Multiple Errands Test; BMET, Baycrest Multiple Errands Test.

In the 2000s, there was a particular interest in questionnaires in child neuropsychology. It is in this context that the BRIEF ("Behavior Rating Inventory of Executive Function" [129]) and the CHEXI ("Childhood Executive Function Inventory" [130]) were constructed in order to measure EFs. The goal was to assess behaviors in multiple contexts over an extended period of time, and in a cost-effective manner. These questionnaires were intended to provide additional information on daily activities. In reality, questionnaire results provide little corroboration of results from performance-based tests [131]. However, it was also possible that questionnaires and performance-based tests assessed different but complementary dimensions of EFs [132]. Indeed, this was the conclusion of the study by Toplak et al. [90], which has since been validated by other researchers (e.g., [132,133]). To explain the low correlations obtained between these two types of measurement tools, Toplak et al. [90] endeavored to understand them from two dissimilar cognitive levels, providing distinct information regarding cognitive functioning. On the one hand, the "reflective" mind would be understandable from rating scales (questionnaire) to highlight behavior in the service of goal achievement. On the other hand, the "algorithmic" mind would be understood using performance-based measures, highlighting the efficiency of processes. Toplak et al. [90] also relied on the distinction made in psychometrics regarding the "typical" performance situation and the "optimal or maximum" performance situation. The former would be closer to rating scales, looking at what a subject would do in a target situation, but not seeking to maximize performance. The latter would be closer to performance-based measures, interested in the maximum performance of subjects. These two tools would then be complementary, the first assessing epistemic regulation and goal prioritization, and the second the efficiency of goal pursuit. The study by Faridi et al. [134] corroborated these findings regarding the evaluation of different aspects. They related the cortical thickness of the posterior parahippocampal gyrus to the working memory score, as concluded from the BRIEF, and the volumes of the amygdala and hippocampus to the working memory score from performance-based tests. In addition, Holochwost and colleagues [84] hypothesized that the low degree of correspondence between questionnaire measures and performance-based tests could be due to the aforementioned discrepancy between trait-like EFs, measured more by questionnaires, and state-like EFs, understood by performance-based tests. Accordingly, performance-based measures and rating scales provide complementary information and should be used together.

In addition to weak correlations between questionnaires and performance-based tests, there is also little correlation among the different tasks designed to assess the same executive process. Those discrepancies cannot be fully explained by the simple intervention of idiosyncratic factors, which is why Niebaum and Munakata [85] invoked the weight of individual differences in personal, historical, and cultural experiences related to Bronfenbrenner's model [37]. With questionnaires, it is possible to consider the child's EFs over a longer period of time in the child's life than with performance-based tests, which reflect an individual's performance at a given moment in time [131,132]. Hetero-questionnaires are also useful for gathering information on the subject from a variety of viewpoints. With children, for example, the possibility of cross-referencing observations from parents, teachers, and other professionals involved in the child's life enables us to view a broad panorama of the child's behavior in a variety of environments. The multiplication of viewpoints through hetero-questionnaires makes it possible to draw more ecological conclusions about a child's functioning in a diversity of environments interacting with a diversity of agents.

However, although self-questionnaires provide information on self-awareness, they may be limited in the context of brain injury, tainting the validity and sensitivity of the tool [87]. Hetero-questionnaires and scales may be subject to bias through the influence of prejudice, personality traits, stress, or emotional involvement of others [90]. In addition, parents' or teachers' familiarity with the child's functioning can also act as a bias, leading to an under- or overestimation of the child's difficulties [87,135]. We should also note that the responses provided by the participant's family and friends, and by the participant themselves, are dependent on their recollection of the events. This highlights another limitation of this type of questionnaire. It is crucial to provide tools that closely reflect both the participant's daily life and their reality.

4.2.2 From Real-World Observation to Intervention: Challenges in Standardizing Ecological Tools?

Given the limitations of the tools mentioned earlier (performance-based tests and questionnaires), it appears that our emerging ecological assessment methods are helping us gain a better understanding of how individuals actually function. This is the case with the Ecological Momentary Assessment (EMA).

The EMA uses a variety of methods to collect data from subjects. For cognitive assessment, it consists of obtaining repeated data on subjects' performance. They are required to complete computerized cognitive exercises directly at home at different times during a given period, which allows for an average performance to be obtained [136]. Other information is also generally collected in parallel (e.g., time of day, emotional state, or stress level), which allows performance to be considered in an integrative and multifactorial framework that is more representative of everyday performance than a paper-and-pencil task performed at a precise time [137]. The collection of additional information on performance, combined with the ability to calculate averages, allows us to approach trait-type

EFs. The results obtained are not limited to a specific moment in time, as is the case with neuropsychological assessments, but are averaged over a longer period of time and combined with other information about the subject that is much more informative about daily functioning than a single performance at a given moment. In this way, it provides information about the subject in the present, which prevents the subjects or their loved ones from thinking about their functioning and difficulties in a general way, as do questionnaires. As a kind of daily journal, the EMA allows information about the subjects to be recorded directly in interaction with their environment. It is therefore not necessary to create a situation to collect performance data, as the data are already gathered in a natural setting (verisimilitude). In addition, the information is mostly collected using digital tools (computers, telephones), which correspond to the equipment naturally used by subjects in their daily lives. Furthermore, the EMA is directly linked to functional consequences as it translates them (veridicality). This enhances its ecological validity, making the EMA a promising method for the ecological assessment of EFs.

Without claiming to be exhaustive, we will discuss a few studies that have used the EMA. In typical populations, we are seeing its use among young adults [138], older adults [139,140], and in adolescents [141]. These studies showed that the value of functional and cognitive assessments is emphasized to highlight fluctuations in EFs over time and across different contexts by obtaining repeated measurements in real-world settings. A study by Warren and Pentz [141] used the EMA method to assess inhibitory control and working memory in children. Their EMA method involved giving participants computerized tasks on smartphones and asking them to do these tasks repeatedly, i.e., inviting them to do them several times. This method allowed participants to do the activities at the time of the week and day that suited them best. The results highlighted weak to strong correlations between EF tasks and the corresponding BRIEF scales. Participants reported a fairly strong interest in this type of task, which they strongly associated with games.

McKinney et al. [142] proposed a narrative review showing that EMA is considered a critical methodology for capturing temporal patterns in EFs, especially when combined with advances in smartphone technology.

Applied research has highlighted the value of this method in identifying everyday EF difficulties in atypical populations. Examples include studies on schizophrenia [143], on a population with multiple sclerosis [144], on a population with type 1 diabetes [136], on a population with generalized anxiety disorder [145], on young people with Attention-Deficit/Hyperactivity Disorder [146]. Essentially, EMAs can capture fluctuations in cognition over time because assessments can be completed multiple times per day or week, and over long periods. Therefore, EMA can demonstrate how external and dynamic factors, such as clinical symptoms, exercise, sleep, stress and the environment, affect cognition on a daily basis and over time.

However, the EMA also has its limitations. First, in the context of cognitive assessment, there is the problem of the test-retest effect. Using the same exercise or type of exercise leads to a learning bias, reflecting probably not everyday functioning, but the subject's specific learning abilities. Second, this method is not suitable for young children, for whom digital tools are not natural. For example, Goldschmidt et al. [147] showed that young people who are overweight or obese and have loss of control eating difficulties find it hard to remember and work with numbers in their day-to-day lives. The relationship between overeating and improved working memory, irrespective of loss of control status, merits further investigation into its temporality and causality. Finally, this method requires active engagement on the part of the subject in regularly performing the exercises, which is not beneficial for subjects who are less engaged in the process.

To improve the ecological validity of EF assessment tools, Chaytor et al. [94] suggested including the "environmental cognitive demands" when assessing children's EFs. These correspond to the expectations of the child's environment, which can vary considerably from one family to another. The expectations of the environment also influence the level of disability felt in daily life. Children's performance is always linked to the demands of their environment. A performance does not have the same value when the environmental expectations are high or low. As we can see, the degree of cognitive functionality is only meaningful if we relate it to the different systems within which the child evolves. By assessing environmental demands, it would be possible to adjust the test requirements to increase the predictive validity of the tools with regard to everyday behavior.

In this perspective, the method used by Duval et al. [148] for developing a new ecological observation grid for preschool children's EF in educational contexts based on the Delphi method is pertinent. It consists of anonymously surveying a panel of experts in the field about the content of the tool in order to increase its content validity. The experts give their opinions and the author is then encouraged to provide them with a new version of the tool, explicitly mentioning the adjustments made. Thus, there are several rounds of feedback leading to minor or major modifications until a consensus is reached among the experts. This method is an alternative to the psychometric method, particularly factor analysis. Indeed, the creation of an ecological assessment tool cannot be subject to traditional psychometric validation since it is based on rating principles other than failure or success. This research is a starting point in the development of new methods adapted to the creation and validation of ecological tools.

5. Discussion

In this article, we have attempted to highlight the reasons why it is crucial to rethink EF assessment tools in light of advancements in developmental psychopathology, child neuropsychology, and neuroscience. A clearer understanding of interactions between biological, environmental, and individual processes in the development of EFs has prompted researchers to develop new ways of conceptualizing EFs, adopting an integrative, dynamic, and multifactorial perspective. These new models invite us to approach children's immediate environment as a means of measuring their EFs in a more ecological way [35,84].

The development of EFs in children is part of a complex network of biological and environmental interactions, which Bronfenbrenner's bioecological model organizes into interdependent systems [37,38]. That model identified integrative mechanisms that promote understanding of the complex processes involved in the development of EFs. Thus, optimal interactions between different systems enable self-regulation of behavior, physiological modulation of stress (which preserves the development of the prefrontal cortex), and repeated cognitive stimulation that mobilizes working memory and cognitive flexibility. Although there is now a wealth of research on the role of the various systems involved in EFs development, the challenge, supported by a biopsychosocial approach, is to understand the complexity of the interactions between the different systems, the factors involved, and their interconnections [84]. This integrative approach also provides a theoretical framework for developing intervention proposals likely to improve EFs development and for devising new assessment tools capable of measuring their development more accurately, given the multiplicity of factors involved.

The concept of ecological validity is important in the evaluation of EFs, and some authors have shown that standardized tasks generally have low ecological validity [94]. Ecological validity consists of two main characteristics: verisimilitude and veridicality [92]. Verisimilitude refers to the match between the requirements of the test features and the test environment and those of the real world. Veridicality captures the degree of prediction between test performance and aspects of everyday functioning. These two features emphasize the match between the test situation and the child's daily life. However, many authors (e.g., [149,150]) warned against using the term "ecological validity" because they felt it was a vague concept with no real conceptual definition and a wide range of uses. Depending on the study, it may refer to prediction in everyday life, to differentiation between different groups, to correlations with other measures, or to face validity. Suchy et al. [150] recommend using the term "criterion/convergent validity", which has two features: concurrent validity (correlation with another test measuring the same concept and having good psychometric qualities) and predictive validity (prediction in everyday life). However, it would be more relevant to talk about divergent validity, since many studies have shown weak correlations between ecological and standardized tools assessing the same processes [151].

Nevertheless, ecological tools, whether task- or questionnaire-based, allow for a much broader investigation of EFs than do performance-based tests. Indeed, unlike performance-based tests that try to target one EF, ecological tools capture a diversity of EFs, which is more ecologically sound because everyday actions call on a range of cognitive abilities: instrumental, mnesic, attentional, and executive [33]. However, the subjective nature of ecological scoring can lead to biased conclusions, as standardization criteria cannot cover all possible situations. Moreover, errors may be multi-determined, especially since this type of evaluation confronts the individual with dual-task situations [100]. Thus, it may be complicated to identify the function underlying the child's deficient performance since the task involves a diversity of processes [87]. Training professionals to use this type of tool is essential to harmonize practices, ratings, and conclusions. However, ecological tools are also able to provide information on the hot aspects of EFs, which is difficult to glean from classical tests. Indeed, placing the child in a familiar situation encourages hot processes to mediate. This stimulates their emotional and cognitive involvement in the task. The conclusions drawn from the child's performance can then be transposed to everyday situations. In this way, ecological assessment provides a solid basis for developing an intervention plan. Unfortunately, the familiar, structured environment in which the subject is immersed should ideally be devoid of distractors, such as noise and the presence of others, which can impair the representativeness of the data collected.

Although there are many tools available to assess EFs across the lifespan (see Table 2 for a non-exhaustive list of ecological tools). However, the consensus regarding the flaws of the tests does not lead to a reliable assessment of the processes in question. Given that tasks requiring the mobilization of EFs involve many executive and non-executive functions, performance-based tests do not allow for a strict understanding of the process. One of the challenges is the development of assessments capable of identifying EFs more specifically, which requires a transformation of the latter. Ecological tools can achieve these objectives: daily diaries, recording of the child in their environments, and real-world activities [88]. Indeed, they are based on concrete situations of daily life. For example, assessment of planning based on a familiar situation, such as preparing a meal, appears to be more ecologically sound than does assessment through a performance-based test, such as the Tower of London.

Ecological tools allow not only a purer assessment but also a better understanding of EFs as they are mobilized in the subjects' daily lives. The development of cleaner and less standardized tools is crucial for better neuropsychological assessment of EFs, especially because of the evolution of neuropsychology, which was originally aimed at diagnosis, gradually tending to predict behaviors in everyday life [89]. To this end, Pinto et al. [149] proposed a reference framework for understanding the ecological validity of an assessment tool, which should encourage authors to develop such tools. The EMA approach is also promising in the ecological assessment of EFs because of its ability to (a) calculate performance averages, (b) allow participants to complete tasks at a time they deem appropriate, and (c) stimulate hot processes through the playful aspect of the medium used. Indeed, EMA would thus be particularly relevant in the assessment of EFs in older children and adolescents, for whom smartphones are of particular interest. The challenge of using this method to assess EFs in children and adolescents is to combine these computerized exercises with everyday activities in order to anchor them more firmly in the subjects' daily lives, with preliminary work to distinguish between the different processes involved.

A lack of awareness and recognition of the usefulness of ecological tools and the dominance of standardized tools are hindrances to their dissemination and use in clinical practice. The development of this type of tool would enable us to assess EFs mobilization more effectively in children from an ecologically valid point of view. We should note that ecological tools are able to provide additional useful information to the clinical approach. It is now becoming almost invaluable to combine performance-based tests and ecological tools in order to better understand the consequences of executive dysfunctions in daily life and to propose accompaniment adapted to the uniqueness of each individual [149].

More research is needed to study the many variables that condition children's executive performance (e.g., cultural influence). Actually, expectations about children's performance are historically and culturally situated. There are many tests or test batteries from other countries in which calibrations are used to draw conclusions about the child's performance in another culture. This approach is not appropriate for a relevant neuropsychological assessment, given the weight of cultural differences. Fernández and Marcopulos [152] showed that using tools (verbal and nonverbal tests) with the same norms from one country to another, even if they are two countries speaking the same language, did not lead to significant results. The validity of the tool, therefore, depends on the context in which it is used. Environmental expectations, whether familial, cultural, or historical, condition children's performance. Indeed, it is important to adopt a holistic and multifactorial understanding of children's performance on EFs measures. It is also important to check that the children are involved in the task, as their engagement is linked to the familiarity they feel [85,153].

Recently, new methods of assessment have been developed to take into account these environmental factors. Indeed, the use of scales that account for behaviors over an extended period of time, direct observation in the natural environment, role-playing based on activities of daily living, and even the use of virtual reality, could lead to a better measurement of EFs in children. Indeed, virtual reality also seems to be a relevant way to ecologically assess EFs in children [154]. A study by Wei et al. [155] compared the performance of adolescents and adults who had suffered a stroke in a shopping activity in a real and virtual context. They concluded that performance on both tasks was broadly equivalent, supporting the interest of virtual reality for ecologically evaluating EFs [145]. However, that study involved only a small number of participants, and further studies are needed to validate the usefulness of virtual reality in the ecological assessment of EFs [145].

In conclusion, this article promotes future directions for the development of new ecological tools that take into account biological (age, sex, etc.), environmental (cultural, familial, and educational context, etc.), and individual (interest, motivation, experience, etc.) factors in a natural context for the assessment of children's EFs. The development of everyday tasks for children or observation scales in natural contexts could be a promising way of approaching this goal, as could the use of EMA. The objective will therefore be to develop new ecological EF assessment tools that are more firmly rooted in a dynamic and integrative perspective, in a natural context, as initiated, for example, by Duval et al. [148] and Warren and Pentz [141]. Consequently, developing ecological assessment tools presents numerous methodological challenges: (a) establishing standards, as with performance-based tests; (b) identifying behaviors linked to different but complementary EFs that help highlight the dynamic aspect of processes; (c) proposing real-time everyday situations; and (d) taking into account both the cold and hot aspects of EFs, such as motivation, level of alertness and fatigue, prior knowledge, and the impact of the examiner's position.

Author Contributions

MW, VD, SSDV, VT, NT, ASD, VJ, and AL contributed to the design of the article. VD, VT, ASD, VJ, and AL participated in securing financial support for the project leading to this publication. MW, VD, SSDV, NT, and AL participated in developing a methodology. VD, NT, and AL participated in supervision. MW, VD, NT, and AL participated in writing the original version of the article and in the pre- and post-publication stages. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

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Conflicts of Interest

The authors declare no conflicts of interest.

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