The Role of Reflection in Promoting Adolescent Self-Regulation

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Abstract

Executive function (EF) – the top-down, conscious control of thought, action and emotion – has been found to be highly predictive of healthy adaptation in adolescence, when many individuals assume increased responsibility for setting and managing the pursuit of their personal goals. We use a developmental social cognitive neuroscience perspective to discuss EF and its relevance to adolescent self-regulation. Specifically, we argue that EF improves as a function of developmental increases in the ability to reflect consciously on one's own perspective and its relation to a broader context of considerations, which in turn is achieved as neural circuits connecting relevant parts of the brain adapt to the environment and change as function of specific, repeated experiences. We conclude with a discussion of the implications of this view for efforts to improve EF in childhood and thereby promote self-regulation in adolescence.

The Role of Reflection in Promoting Adolescent Self-Regulation

Research on goal pursuit (Gollwitzer & Oettingen, 2011; Oettingen, 2012) has identified concrete strategies for improving goal achievement that emphasize the role of rule use in the service of goal pursuit. From this perspective, rules play an important role in representing and transforming the relation between a desired future and the current reality (Oettingen, 1999, 2012), and also in formulating specific plans for engaging in goal-directed behavior (Gollwitzer, 1999; Gollwitzer & Oettingen, 2011). Research indicates that adolescents are more successful at achieving their goals when these rule use strategies are implemented (e.g., Duckworth, Grant, Loew, Oettingen, & Gollwitzer, 2011).

In this chapter, we provide a developmental social cognitive neuroscience perspective on self-regulation that focuses on the nature and development of executive function. Executive function (EF) – the top-down, conscious control of thought, action and emotion – continues to develop well into adolescence and may become increasingly important for healthy adaptation as adolescents become more responsible for setting and managing the pursuit of personal goals. An understanding of the mechanisms underlying EF and its development has the potential to inform the creation of more effective interventions for promoting self-regulation, supporting and complementing the self-regulation strategies identified by Gollwitzer, Oettingen, and colleagues. We first summarize relevant research on the protracted development of EF in childhood and adolescence and then describe a theoretical model, the Iterative Reprocessing Model, that addresses how improvements in self-reflection, mediated by the growth and refinement of neural networks involving increasingly anterior regions of prefrontal cortex (PFC), make the development of EF possible. We conclude by offering suggestions for an integrative approach to enhancing self-regulation in adolescence that takes into account what is now known about neural plasticity and the neurocognitive processes involved in EF. Specifically, interventions promoting reflection suggest a promising approach that can be incorporated with other strategies to maximize goal achievement in adolescents.

EF and Its Importance Across Development

EF is essential for adaptive human functioning, from completing the most mundane activities to solving the most challenging problems, and a key feature of EF is keeping one's goals and the current context clearly in mind—consciously reflecting on them. Conscious reflection, which depends on neural networks involving hierarchically arranged regions of prefrontal cortex, is required, for example, when one attempts to suppress a spontaneous emotional response out of consideration for someone's feelings. But even the execution of relatively routine behavioral plans requires some degree of conscious reflection to avoid interference from misleading environmental cues. For example, holding a container of orange juice in hand when one is preparing a bowl of cereal for breakfast could easily lead to error if one does not maintain some awareness of the situation.

Although the need for EF is present throughout childhood and across the lifespan, there are periods during which the demands placed on EF are relatively high, and during which performance on laboratory measures of EF improves relatively rapidly. During the preschool years, for example, children typically show rapidly increasing degrees of control over thought, emotion, and action, as they prepare for the transition to school, which itself places substantial new demands on EF in the context of learning and cooperating with peers. It is now well documented that EF undergoes particularly rapid developmental change during this period (Zelazo et al., 2013). Similarly, adolescence is a period during which a range of new influences—both endogenous and exogenous to the individual—must be managed on the fly. For example, during the transition to adolescence, social stimuli become increasingly salient, and children become increasingly sensitive to peer approval (Nelson, Leibenluft, McClure, & Pine, 2005). At the same time, however, children are provided with new opportunities to exercise independence and take risks. In the presence of peers, choices can be biased towards risk, leading to undesirable outcomes (Gardner & Steinberg, 2005), so the need for EF is especially strong. Research also suggests that the transition to adolescence is another period during which EF develops relatively rapidly (Zelazo et al., 2013). EF development during both periods co-occurs with changes in the neural structures that support EF, and research on neural plasticity (e.g., Huttenlocher, 2002) suggests that EF and prefrontal networks develop particularly rapidly during these times precisely because this development is demanded by circumstances, and hence, EF is exercised vigorously.

In sum, EF is a critical ability that develops markedly in early childhood and adolescence, likely as a result of behavioral and neural adaptation to the changing demands of the environment. By addressing the neurocognitive processes that underlie goal-directed behavior, and revealing the ways in which these processes grow through interactions with the environment, a developmental social cognitive neuroscience perspective offers clues about how best to facilitate the healthy development of EF in adolescents. In the next section, we discuss the processes underlying EF and its development.

The Development of EF in Early Childhood

Recent research using measures of EF that are suitable for individuals aged 3 to 85 years confirms that EF improves most rapidly during the preschool period but continues to develop during adolescence and beyond (Zelazo et al., 2013). These changes in EF co-occur with substantial structural and functional changes in neural systems involving PFC (Carlson, Zelazo, & Faja, 2013). Performance on one such measure of EF, the Dimensional Change Card Sort task (DCCS) (Zelazo, 2006), is shown in Figure 1. In the DCCS, children first sort bivalent test cards (e.g., red rabbits and blue boats) according to one dimension (e.g., by shape) for several trials, and then are instructed to switch to sorting the same cards according to a new set of rules (e.g., by color). Performance on this task at this age is typically scored as the number of post-switch test cards sorted correctly. On the post-switch phase, 3-year-olds typically continue to sort the test cards according to the initial rule set, despite being informed of the new rules before every trial and demonstrating knowledge of the new rules (Zelazo, Frye, & Rapus, 1996; Zelazo, Müller, Frye, & Marcovitch, 2003). By contrast, most 4- and 5-year-olds switch to the new rules. Performance on this task remains effortful, however, and while older children and adults usually maintain high levels of accuracy, they need to slow down in order to do so. Reaction time on this task decreases with increasing age until early adulthood.

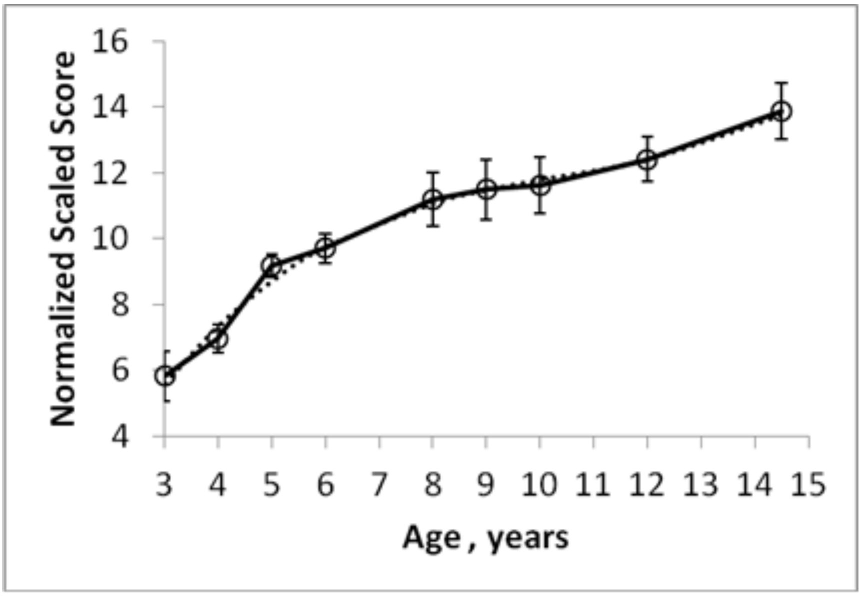

Figure 1. Performance on the NIH Toolbox DCCS Test across age groups. Pediatric data from a cross-sectional validation study of 476 individuals, ages 3 to 85 years. Performance was indexed using a two-vector method in which individuals that achieved a high level of accuracy in the post-switch phase of the task (≥ 80% cards sorted correctly in the post-switch phase) were primarily assessed based on their reaction time, with slower RTs indicating more effort, whereas children who sorted < 80% of cards correctly were assessed based on the percentage they achieved. These measures were converted to a normalized scaled score to make comparison across the different measures possible. Error bars are +/- 2 standard errors. Reproduced with permission from: "NIH Toolbox Cognition Battery (NIHTB-CB): measuring executive function and attention." by P. D. Zelazo, J. E. Anderson, J. Richler, K. Wallner-Allen, J. L. Beaumont, and S. Weintraub, 2013, *National Institutes of Health Toolbox Cognition Battery (NIHTB-CB): Validation for children between 3 and 15 years. Monographs of the Society for Research in Child Development*, p. 27.

The Iterative Reprocessing Model of the Development of EF

Research on EF generally supports the seminal ideas of Vygotsky (1962) and Luria (1959, 1961) concerning the importance of verbal processes in the exercise and development of self-regulation, finding, for example, that with age children increasingly use verbalization strategically to maintain task information in mind (Karbach & Kray, 2007), and that blocking the use of inner speech disrupts cognitive control in children and adults (Emerson & Miyake, 2003; Kray, Eber, & Karbach, 2008). According to one view, the Iterative Reprocessing model (e.g., Cunningham & Zelazo, 2007), EF involves the formulation and maintenance in working memory of explicit action-oriented rules, and the development of EF is made possible, in part, by increases in the hierarchical complexity of the rules that can be used (Zelazo et al., 2003). These increases in rule complexity are, in turn, made possible by increases in the ease with which children can reflect on rules and consider them in relation to a larger context (Zelazo, 2004). Increases in reflection correspond to the iterative reprocessing of information via neural circuits that coordinate hierarchically arranged regions of PFC (Bunge & Zelazo, 2006).

With more reprocessing of information, more details are perceived and integrated into one's representation of their experience. For example, if one is experiencing a particular stimulus (e.g., a red rabbit) in the relative absence of reflection, one may only notice a single salient feature, such as its kind. Upon further reflection, however, and with further iterations of reprocessing via neural circuits involving PFC, other aspects of the stimulus, such as the color and the other categories to which it belongs (e.g., red thing, animal, etc.), may become integrated into one's conscious representation. Figure 2 illustrates how the reprocessing of information unfolds in time and allows for the construal of a stimulus within a larger context, leading to a more richly nuanced experience and, importantly, the ability to select and amplify attention to different aspects of a stimulus.

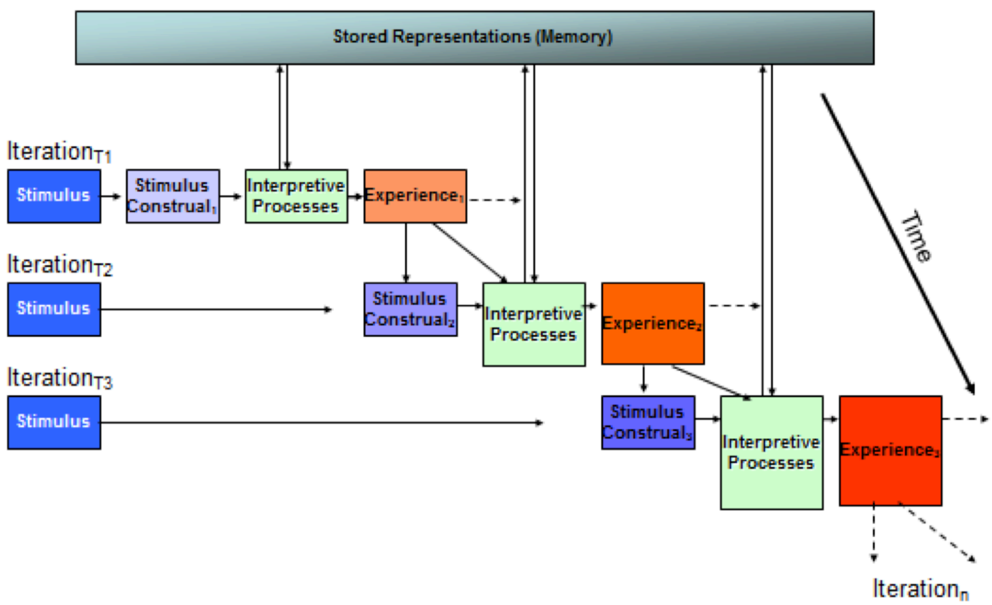

Figure 2. Reflection unfolds in time through a series of iterations. The iterative reprocessing of information about a stimulus allows more aspects of the stimulus and of the context in which it occurs to be integrated into the experience of the stimulus. Adapted with permission from “The Iterative Reprocessing Model: A multi-level framework for attitudes and evaluation” by W. A. Cunningham, P. D. Zelazo, D. J. Packer, and J. J. van Bavel, 2007, *Social Cognition, 25,* p.740.

With reflection, as children integrate more features of a stimulus into their representation of it, or as they consider the current context in relation to other contexts (e.g., the previous rules), they will be better positioned to formulate more complex, nested systems of rules that accurately represent the relevant contingencies (e.g., "If I'm playing the shape game, then rabbits go with rabbits and boats go with boats; but if I'm playing the color game, red ones go with red ones, and blue with blue"). These rule representations are verbally mediated in that they are represented internally via self-directed speech in working memory. Such complex rule representations allow for more flexibility and control in a wider range of situations than previously possible. In the absence of adequate reflection, children are limited to responding according to simple rules, particularly those that are activated in mind quickly. If they fail to reflect on their knowledge of the rules in relation to one another, then they will be unlikely to formulate a higher-order rule that integrates the simple rule sets. Figure 3 illustrates how the ability to integrate knowledge structures through the formulation of higher order rules permits the top-down selection of situation-appropriate rules while inhibiting the tendency to select inappropriate rules that are elicited or primed in a bottom-up fashion.

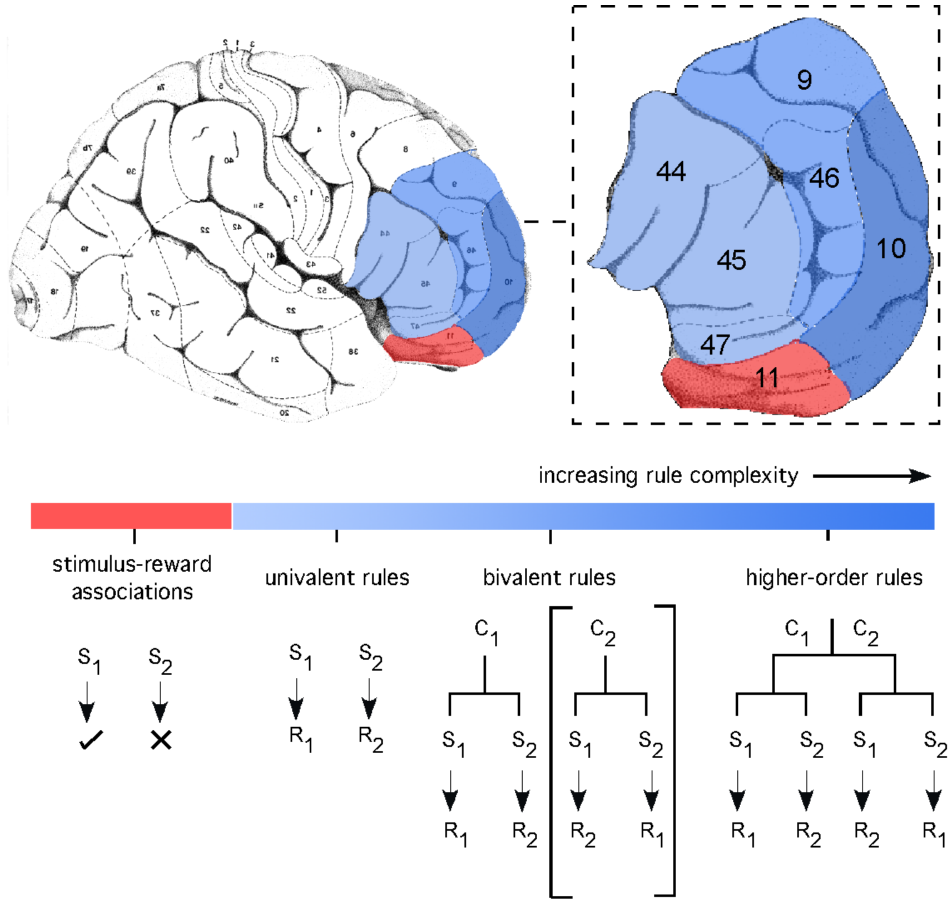

Figure 3. A hierarchical model of rule representation in PFC. A lateral view of the human brain is depicted at the top of the figure, with regions of PFC identified by the Brodmann areas (BA) that comprise them: Orbitofrontal cortex (BA 11), ventrolateral PFC (BA 44, 45, 47), dorsolateral PFC (BA 9, 46), and rostrolateral PFC (BA 10). The PFC regions are shown in various shades of gray, indicating which types of rules they represent. Rule structures are depicted below, with darker shades of gray indicating increasing levels of rule complexity. The formulation and maintenance in working memory of more complex rules depends on the iterative reprocessing of information through a series of levels of consciousness, which in turn depends on the recruitment of additional regions of

PFC into an increasingly complex hierarchy of PFC activation. Note: S = stimulus; check = reward; cross = nonreward; R = response; C = context, or task set. Brackets indicate a bivalent rule that is currently being ignored. Reprinted with permission from "A brain-based account of the development of rule use in childhood." by S. A. Bunge and P. D. Zelazo, 2006, *Current Directions in Psychological Science, 15,* p. 119.

Put another way, reflection allows children to gain psychological distance in a task situation where specific response tendencies are strongly evoked (i.e., by the stimulus and previous experience with it). Without reflection, children tend to respond to the most salient, easily processed aspects of a stimulus; with reflection, they can notice other relevant aspects and respond accordingly.

The development of reflective reprocessing and EF co-occurs with the development of lateral PFC, and both EF (Luciana, Conklin, Hooper, & Yarger, 2005; Prencipe et al., 2011) and PFC continue to develop into adulthood (Gogtay et al., 2004). Bunge and Zelazo (2006) proposed that the ability to represent rules at differing degrees of complexity is subserved by networks involving hierarchically arranged regions of cortex within PFC, with some lower-order regions being important for representing (and updating) stimulus-reward associations, and with more higher-order, anterior regions, such as rostrolateral PFC, important for the representation of relatively complex rules. Figure 3 also illustrates how rules of differing levels of complexity map onto specific regions of cortex. In the next three sections, we summarize evidence supporting the Iterative Reprocessing model of the development of EF, and use these findings to consider new ideas about how EF in the adolescent period might be shaped by new preferences, experiences and opportunities to reflect.

Experience, Reflection, and Rule Use in Childhood

The Iterative Reprocessing (IR) model provides a brain-based account of developmental transitions in the ability to use complex rules to govern behavior in a deliberate fashion, and this model suggests that experience plays a crucial role in increasing the ease with which people engage in reflection. While other theories have stressed the importance of social experience in cognitive and social development (e.g., Lev Vygotsky, Albert Bandura, and Walter Mischel), the IR model emphasizes the interaction between repeated experiences of any type (verbal, social, and otherwise) and the neural substrates underlying reflective processes that in turn support EF. The effects of experience on reflection and EF have been demonstrated clearly in research with infants and children. For example, evidence suggests that experience with the A-not-B task may lead to improved performance on the task, through reflection. In this task, infants observe an object being hidden several times at one location (location A) before it is hidden conspicuously at a new location (B). Despite witnessing where the object was last hidden, young infants typically search perseveratively in the A location. However, Marcovitch and Zelazo (2003) found that infants' performance on the A-not-B task changes nonlinearly (U shaped) as a function of the number of A trials. As the number of A trials increases, the likelihood of perseveration to location A first increases and then decreases. This was modeled as follows: While the tendency to reach perseveratively to A becomes more potent with repeated practice, each A trial also provides another opportunity for reflection on the task, increasing the likelihood that children will notice the task structure and the fact that the location has changed. Reflection supports their ability to keep the trial-specific information about the object's current location (the B location) in mind.

In another series of studies (see Jacques & Zelazo, 2005), young children who were given the opportunity to label their point of view on a situation were better able to consider a new, competing point of view. Children completed a modified version of the Flexible Item Selection Task (FIST; Jacques & Zelazo, 2001). In the standard version, three pictures are presented, two of which match on shape, and two of which match on size, and the child is asked to show the experimenter two pictures that match in one way, followed by two pictures that match in another way. One of the stimuli, the pivot stimulus, had to be construed differently in each selection. The youngest children performed poorly on the second selection, evidently failing to consider the stimuli in terms of a new dimension once they had been construed in terms of another (initial) dimension. In the new version, some children were asked to articulate the basis for their first selection (i.e., "Why do these pictures go together?"). Children who provided labels performed better on the second selection, suggesting that being asked to label their perspective with respect to the task stimuli prompted reflection, which in turn enabled children to perceive other features on which the stimuli matched.

Experience, Neural Plasticity and EF

As noted, periods of relatively rapid change in EF and underlying neural structures co-occur with recognized sociocultural transitions, including the transition to a structured school environment, the transition to adolescence, and perhaps, the transition to adult life. Research on neural plasticity suggests that cognitive development, including the development of EF, corresponds to a set of adaptations in an inherently plastic or malleable organ, the brain. The importance of neural plasticity has long been recognized (e.g., Hebb, 1949), and there is now considerable evidence of the role of experience in brain development (e.g., from enrichment studies; see Greenough, Black, & Wallace, 1987; from sensory deprivation studies see Wiesel & Hubel, 1963), including numerous correlational and experimental studies with human beings (for an overview see May, 2011). For example, the number of hours spent practicing the piano (especially as a child) has been found to be related to myelination (the increase in white matter around the axon of neurons, supporting more rapid neural firing) with different neural regions being implicated at different ages (Bengtsson et al., 2005). Findings like these suggest that we grow our brains by using them, and that we grow our brains in particular ways by using them in particular ways.

When our culture demands that we exhibit EF, we see a rapid growth in EF. Moreover, a growing body of research has now demonstrated conclusively that the development of EF can be cultivated through exercises that require the use of prefrontal cortical circuits. Much of this research has focused on the preschool period (for an overview see Diamond & Lee, 2011). For example, Rueda, Rothbart, McCandliss, Saccomanno, and Posner (2005) improved 4- and 6-year-olds’ performance on a computerized attention task with five training sessions using computerized games. Children in the training condition showed improvement on an attention task and a measure of general intelligence, as well as more adult-like patterns in an event-related potential (ERP) (the N2) located over frontoparietal and prefrontal areas.

Prefrontal cortical plasticity is clearly not limited to the preschool period, however, and an example of a successful intervention with older children and adults is CogMed, designed to train working memory. Following 5 weeks of training, Klingberg et al. (2005) found improved working memory and reduced Attention Deficit/Hyperactivity Disorder (ADHD) symptomatology in a group of 7- to 12-year-olds with ADHD. In a study of CogMed with adults Olesen, Westerberg, and Klingberg (2003) found training-related changes in activity in cortical regions known to be involved in working memory (i.e., increases in activity in frontal and parietal areas as well as decreases in activity in the cingulate cortex).

Experience, Reflection, and EF in Adolescence

The above findings suggest new ways to conceptualize developmental change in EF during the transition to adolescence, a relatively unique developmental period that is also, like the transition to school, marked by increasing demands on children's EF. We emphasize new situational demands that provide opportunities for children to practice engaging in the iterative reprocessing of potentially relevant information prior to judgment or action. For example, an adolescent may encounter new situations in which EF is required for adaptive functioning, such as rapidly tracking the intentions of peers in conversation. In experiencing these situations, adolescents have the opportunity to notice and hold in mind various information, both salient (e.g., literal meaning implied directly by words that are spoken) and relatively peripheral (e.g., subtle facial expressions, intonation, implied information). With iterative reprocessing, adolescents are able to notice less obvious information, amplify their attention to it, and use it to guide judgments of intended meaning. Furthermore, with use, the neural circuits that make this possible become increasingly efficient, initiating a developmental cascade of events: children experience more situations in which reflective processing is useful for adaptive functioning, and gain further practice at engaging in reflection at opportune times. Adolescents also undergo physical and hormonal changes that propel them in new directions, increasing the salience of social stimuli and engendering new valuations, and, in turn, the promise of new rewards and punishments. For example, peers and potential sexual partners are increasingly central in adolescents' lives. As such, further development of adolescents' social cognitive skills likely results from increasing engagement of existing capacities in the service of understanding and predicting the behavior of those around them.

Reflection occurs when there is a problem to be solved—something new or unexpected happens and we are motivated to make sense of it. Novel experiences tend to capture our attention, and we may contrast and compare them with other experiences. Sensation seeking in adolescence may lead to developmental increases in reflection simply by increasing the number and range of novel stimuli and situations. For example, initial social interactions with the opposite sex may be experienced as very motivating and inherently rewarding, which promotes further engagement. Extended experience may result in opportunities to further notice and appreciate the opposite sex and develop new preferences and pursuits, such as romantic relationships, and to develop associated skills. Importantly, taking risks because of the promise of new, pleasurable sensations, such as speeding while driving or shoplifting, provides opportunities for reflection that can lead to more adaptive decision making in the future. Of course, the increase in opportunities for reflection does not necessarily imply that it will occur, and if it does, that does not guarantee that adolescents will necessarily make better choices – rather, what reflection affords is increasing flexibility in the selection of goals. Depending on the context in which one is developing, the pursuit and achievement of such goals may yield very different outcomes. As we discuss in more detail in a later section of this chapter, reflection may be used in conjunction with mental contrasting of options to increase the flexible selection of goals.

The development of reflection during adolescence may also be facilitated by ongoing conceptual development in the domain of self-understanding. Beginning in infancy and progressing through early childhood, children acquire an increasingly complex explicit understanding of the self with respect to the world and others (e.g., Amsterdam, 1972; Damon & Hart, 1982; Povinelli, Landau, & Perilloux, 1996; Rochat, Broesch, & Jayne, 2012). The idea of the "self-as-knower", that is, as the processor, organizer, and interpreter of information, capable of voluntary action, falls under what James (1892/1961) referred to as the "I" aspect of the self. In contemporary terminology, we might talk about this understanding as flowing from the capacity to apprehend the self from a "psychologically distant" perspective, where the self of "the here and now" is transcended via conceptualizations at different levels of abstraction (Trope & Liberman, 2010). For example, one can construe the self objectively, as persisting across time and space, and as a mind that thinks, feels, and does, and also reflects. It is plausible that such self-understanding may contribute to the ability to exercise deliberate control over one's actions both in early childhood, as Perner, Lang and Kloo (2002) have suggested, and also in adolescence. Facility in thinking about the self from a more abstract perspective may permit one to achieve the necessary psychological distance from immediate experience to override habitual or prepotent tendencies that are evoked by specific environments and situations.

Research with young children clearly demonstrates that conscious control of thought and action is associated with developments in awareness of self and other. Children who reflect on their own and others' mental states perform better on EF tasks, for example (e.g., Carlson & Moses, 2001; Frye, Zelazo, & Palfai, 1995; Perner & Lang, 1999). According to Zelazo and Sommerville (2001) children come to understand that the self exists independently of the world and that both are situated in time. Such understanding is thought to be made possible by increases in reflection which supports controlled thought and action directly, but may also support them indirectly by providing additional conceptual scaffolding for subsequent developments in reflection and control. Indeed, these interrelated functions—reflection, conceptual understanding of the subjective self in time (vis-à-vis various objects), and EF—likely bootstrap one another during adolescence, a period during which self-understanding develops rapidly (Damon & Hart, 1982).

Experience and Reflection in the Development of Hot EF in Adolescence

As in early childhood, the development of EF in adolescence and beyond also depends on increases in the efficiency of networks involved in the reflective reprocessing of information. Whereas children show salient changes in the upper limits of their reflective capacity as useful networks are first established, adolescence is marked more by increases in the probability of reflection in any given situation, and by the generalization of reflective reprocessing skills to situations in which there are high levels of emotional arousal. Indeed, a distinction has been drawn between the top-down processes that operate in motivationally and emotionally significant high-stakes situations, so-called “hot EF”, and those that operate in more decontextualized, abstract, or symbolic situations, termed “cool EF” (Zelazo & Carlson, 2012; Zelazo & Müller, 2002). This distinction is supported by numerous lesion studies, neuroimaging research, and behavioral research with children. For example, 3-year-olds, but not 4-year-olds, have difficulty when required to point to a smaller reward (e.g., two jelly beans) rather than a larger reward (e.g., five jelly beans) in order to get the larger reward, but Carlson, Davis, and Leach (2005) found that when the rewards were replaced with abstract symbols (i.e., “cooler” representations of the rewards), 3-year-olds’ performance improved significantly.

Some research suggests that adolescents may achieve mature performance on tasks that require cool EF earlier than those that require hot EF. Specifically, when there are opportunities for social or monetary rewards, adolescents may be less likely to reflect and exercise EF. Luciana et al. (2005) found that children reached peak performance at a later age on the Iowa Gambling task (between 14-17 years) than on cool EF measures such as digit span and Go/No-Go. Similar discrepancies between hot and cool EF developmental trajectories were identified by Prencipe et al. (2011) in a sample of children aged 8 to 15 years. Peer presence has also been shown to affect adolescents’ decision-making ability adversely, leading to more risky choices than when peers are not present (Gardner & Steinberg, 2005).

Research indicates that hot EF requires different brain systems than tasks involving cool EF, including orbitofrontal cortex and other medial frontal regions (Happaney, Zelazo, & Stuss, 2004; Zelazo & Müller, 2002), and according to the

Iterative Reprocessing model, adolescents have more difficulty exercising hot versus cool EF because the neural circuitry underlying the engagement of reflective processes in motivationally significant situations develops later, and because those situations are often inherently more demanding. This developmental lag in the establishment of the reflection circuitry required for hot EF may be due in part to adolescents' inexperience identifying and specifying appropriate goals in motivated contexts, to their inexperience identifying cues to risk, and in general to their relative inexperience engaging and practicing reflection in hot contexts. It may also be simply that hot EF tends to be hotter than cool EF because it involves both reflection and emotion regulation (whereas cool EF tends to involve just reflection). For example, in the Iowa Gambling Task, decks that initially appear advantageous are gradually revealed to be disadvantageous. Performance is influenced by both top-down and bottom-up processes (e.g., Bechara, Damasio, Damasio, & Anderson, 1994; Kerr & Zelazo, 2004; Manes et al., 2002). From the perspective of the Iterative Reprocessing model, performance can be viewed as involving reflection on the structure of the task (e.g., recognizing which decks are disadvantageous over the long-term). Prolonged experience with the task, or practice with versions where the "hot" component (e.g., points, fake money, real money) is manipulated (e.g., from cool to hot, from lower to higher motivational significance), may help children develop the tendency to reflect even in motivated contexts.

It should be noted, however, that another crucial way that cool EF tasks tend to differ from hot EF tasks is that cool EF tasks tend to involve more well-defined problems. In cool EF laboratory tasks, for example, appropriate goals are often specified for the child, but this is not always the case in hot EF tasks, and even when it is, children may need to override salient, competing goals. For example, when completing a video driving game in the presence of a peer, the stated goal of the task may be to arrive safely, but children likely also possess the goal of impressing their peer and highly value the peer's acceptance relative to the outcome of arriving safely in a merely virtual world. In other words, failure to achieve the appropriate goal as defined by the experimenter may be less a function of deficits in self-regulation and more related to real differences in adolescents' weighting of different choices and outcomes (Moore & Gullone, 1996).

It might be argued that reflection may not be necessary or even beneficial in some situations calling for self-regulation, particularly in more demanding hot contexts in which a fast, automatic response might be most desirable. For example, in a situation in which an adolescent is offered a cigarette by a peer, the most effective self-regulatory response in the immediate context might be to quickly and unreflectively respond "no", versus engaging in reflection about why or why not one should smoke. However, from the perspective of our model, while the unreflective mode of achieving self-regulation may allow one to avoid a poor outcome in a particular situation, such an approach would likely have limited efficacy, given the complexity of peer dynamics and temptation. Considering this scenario from the perspective of our theory, with the benefit of reflection, an adolescent offered a cigarette would likely be able to conjure multiple options for responding and their associated outcomes and pursue the most adaptive path that is consistent with multiple competing goals (e.g., maintain peer acceptance and avoid smoking). For example, this might result in the choice of nonchalantly taking the cigarette and expressing, for the benefit of observing peers, indifference to the experience. This might achieve the goal of maintaining peer acceptance by showing that one is not afraid to engage in a risky activity while also privately observing the personal goal of not smoking.

Thus, the establishment of neural circuitry underlying reflection in motivationally and emotionally significant contexts may depend in part on the accumulation of experiences in which there is the opportunity to recognize the differential outcomes associated with the pursuit of risky versus more adaptive, future-oriented goals. This is not to say that the tendency toward reflection will only emerge through actual risk taking and the experience of negative consequences. In the next section we discuss how what we know about the role of experience and reflection in the development of EF, expressed in the Iterative Reprocessing model, can be combined with strategies for promoting appropriate goal pursuit to maximize adolescents' propensity to engage reflective processes and set and achieve appropriate goals.

Utility of Iterative Reprocessing Model in Thinking about Strategies to Improve Rule Use in Adolescence: Implementation Intentions and Fantasy Realization

We first briefly summarize two prominent approaches to improving rule use in the service of goal achievement (Oettingen & Gollwitzer, 2010; Gollwitzer & Oettingen, 2011) and then compare and contrast these approaches with the Iterative Reprocessing model. In doing so, we argue that the integration of these different approaches to rule use will increase the efficacy of interventions to promote goal achievement in adolescence.

On Gollwitzer's view, an effective approach to goal attainment is the use of conditional rules to formulate behavioral plans to be executed in the presence of a situational cue (Gollwitzer, 1999; Gollwitzer & Oettingen, 2011). Such plans make goal attainment more likely in that they reduce the necessity for cognitive effort at the time of action. Once such rules are established, as implementation intentions, the relevant actions are triggered relatively automatically by a pre-specified cue, and self-regulation is essentially offloaded onto the environment. For example, if one is on a diet and has the goal of avoiding sweets, formulating a plan specifying precisely what one will do when confronted with the tempting treat increases the chance of success in part because one does not have to engage reflective processes. That is, upon finding oneself in a situation where one is confronted by temptation, instead of having to recall one's goal and actively resist temptation using some strategy formulated on the spot, the temptation will prime a previously specified action plan (e.g., If I end up somewhere where there are treats, eat this granola bar instead).

The foregoing assumes that one is already committed to a goal and strives for it and only needs to articulate an effective plan to attain it. However, one can also intervene via rule use at the level of goal commitment. According to Fantasy Realization Theory (Oettingen, 1999, 2012), the most adaptive self-regulation strategy for forming goal commitment involves mental contrasting of desired future and current reality. Cognitive elaboration of the relation between these two states will increase activation of expectations concerning the likelihood of taking the required actions to achieve the desired state, which in turn will feed into goal commitment with subsequent goal striving. For example, imagine I want to lose weight (desired future) but I like to eat processed food regularly and in large quantities (current reality). If I want to achieve my goal, I need to stop eating processed food and reduce my portion sizes (an integrative solution that emerges after cognitive elaboration of the desired future and the current reality); I determine that it is likely that I can do this, which enhances my goal commitment and subsequent goal striving. Thus, rules need to be formulated to link the desired future with current reality such that there is a plan to transform reality into the desired future. Recent research further indicates that such mental contrasting influences goal achievement by shaping an individual's conception of the meaning of reality, specifically by casting it as marked by obstacle(s) (Kappes, Wendt, Reinelt, & Oettingen, 2013), and thus rule representations will explicitly address obstacles in current reality. For example, continuing with the example above, the meaning of current reality as obstacle could be that I have a strong habit of eating fast food on my way home from school, and it is this habit that is a barrier to my desire to lose weight.

These approaches have considerable potential for use with adolescents as a means to facilitate adolescent goal achievement, and indeed such efforts have been pursued to good effect (Duckworth et al., 2011). By addressing the neurocognitive processes that underlie goal-directed behavior, however, and revealing the ways in which these processes grow through interactions with the environment, a developmental social cognitive neuroscience perspective such as the Iterative Reprocessing model suggests ways to complement the strategies studied by Gollwitzer (1999; Gollwitzer & Oettingen, 2011) and Oettingen (1999; 2012) and generally to facilitate the healthy development of problem solving.

A Developmental Social Cognitive Neuroscience Perspective

From the perspective of contemporary developmental neuroscience, neurocognitive development can be seen as a dynamic process of adaptation wherein neural systems are constructed (by the child) in a use-dependent fashion; fibers connecting regions within a network (and between networks) are myelinated, and there appear to be both experience-expectant and experience-dependent processes wherein synapses are formed and unused synapses are pruned (Greenough et al., 1987). These processes are accompanied by corresponding changes in neurocognitive function. For example, as described in further detail below in the section on training EF through reflection, in addition to improving EF performance, training EF in early childhood using tasks like the DCCS produces changes in the amplitude of an EF-related component of the event-related potential (ERP), the N2, which reflects activation of the anterior cingulate cortex and is reliably elicited by detection of conflict (Espinet, Anderson, & Zelazo, 2012; Rueda et al., 2005).

During adolescence, it is possible to support the ongoing development of the reflective reprocessing of information about a situation prior to judgment or action, and indeed, as part of the processes of forming goal commitment with subsequent goal striving and the formulation of implementation intentions. As noted by the Iterative Reprocessing model, reflection is important for recognizing relevant aspects of situations that need to be accounted for in the formulation of goals and rules for attaining them; recognizing and keeping in mind all relevant contingencies so that new cues won't lead to plan failure; exerting flexibility in the restructuring of rules when needed, to avoid perseveration (e.g., when results of plan are not desired; when plan is no longer appropriate); recognizing conflicts among goals and plans; recognizing and more adequately conceptualizing obstacles to a desired future; and thinking more abstractly about situational cues so that overly specific cues don't lead to failure to act. To the extent that each of these skills depends on still-developing processes of reflection, and given that reflection— engaging in the iterative reprocessing of information prior to judgment or action—is a skill that can be acquired, the Iterative Reprocessing model suggests that reflection be a target of training.

Research on “brain training” (Bryck & Fisher, 2012) indicates that effective interventions generally share a number of characteristics: they motivate children (but not too much) to pursue a series of goals, each posing a greater challenge to children’s developing skills. This adaptive, dynamic adjustment approach provides children with developmentally appropriate challenges. To increase the likelihood of generalization of trained skills, these skills need to be exercised in a variety of contexts, ideally including real-world contexts. Under these circumstances, it seems, it is possible to train high-level skills like reflective reprocessing, and accelerate their development, with corresponding neural changes that reflect myelination, changes in synapses (connections among neurons), and synaptic pruning (reduction of connections among neurons that are not used). A consequence is that trained networks become more efficient, so reflective reprocessing occurs more automatically and more quickly, providing more time for thoughtful reflection prior to overt action or to decision making.

Complementing Advance Planning with Reflection Training

The theories of goal pursuit proposed by Gollwitzer (1999; Gollwitzer & Oettingen, 2011) and Oettingen (1999; 2012) emphasize planning and setting the stage for successful goal pursuit, and these strategies appear to be effective. Indeed, given that adolescents’ EF is still developing, it may be safer to rely on strategies that may be implemented relatively automatically in hot contexts. At the same time, however, situations and needs do change, and successful goal achievement also depends on one’s ability to reflect, display cognitive flexibility, and adapt to changing situations. Reflection is needed both at the outset of advance planning and at later stages of goal pursuit to formulate adequate plans and to exert flexibility when plans need to be modified or abandoned. We believe that a model of goal pursuit in adolescence that captures the role of reflection as a core developmental process will better support efforts to promote healthy development in adolescence. For example, in line with recent findings, reflection may help adolescents perceive potential obstacles to their goals and represent them as part of their current reality construal (Kappes et al., 2013), which may in turn foster goal achievement through identifying and acting on effective means to overcome these obstacles (Kappes et al., 2012).

Improving EF through Promotion of Reflection

An important implication of the Iterative Reprocessing model is that EF is plastic insofar as it can be improved through the use of the neural circuitry supporting the iterative reprocessing of information. Several studies lend support to the Iterative Reprocessing model, indicating that intervening to promote reflection in early childhood is a promising approach for improving EF. Espinet, Anderson and Zelazo (2013) assigned children who failed the DCCS to one of three conditions: an experimental condition that consisted of reflection training in the context of the DCCS (but with different shapes and colors), and two control conditions using the DCCS together with minimal feedback or mere practice with no feedback. It was hypothesized that children who received reflection training would show significant improvement in performance on a subsequent administration of the DCCS, unlike children in the two control conditions. The findings were consistent with the hypothesis and also show unique effects of training on children's ERPs, such that training produced not only behavioral improvements, but also reductions in N2 amplitude, compared to children who simply received corrective feedback: “That’s right/that’s wrong. You (are supposed to) press the button with the apple on it (experimenter points to correct button).” The N2 has been interpreted as an index of conflict detection. Children who pass the DCCS may resolve the conflict inherent in the task more efficiently than children who fail, resulting in smaller N2 amplitudes. One possibility is that for these children, conflict detection initiated reflection and higher-order rule use (mediated by lateral prefrontal cortical networks) that effectively resolved the conflict inherent in the stimuli and down-regulated ACC activation (Badre & D’Esposito, 2007; Botvinick, 2008; Bunge & Zelazo, 2006; Christoff & Gabrieli, 2000; Koechlin, Ody, & Kouneiher, 2003).

Mindfulness meditation training has also been found to promote EF in an emotional context. Ortner, Kilner, and Zelazo (2007) randomly assigned 68 young adults to one of three groups: mindfulness meditation training, an active control condition (relaxation meditation training), and a waiting list control (who received training at a later date). Training involved 7 weeks of classes plus homework. Participants in all groups completed cognitive-emotional tasks both prior to and after the training period. One measure was the Emotional Interference Task (EIT; Buodo, Sarlo, & Palomba, 2002) in which participants viewed several pictures of positive, negative and neutral valence for 6 seconds each. A tone was presented 1 to 4 seconds after the picture onset, and participants were asked to make judgments about whether the tone was high or low pitched. Typically, reaction times are slower on trials where unpleasant pictures are presented. Ortner et al. (2007) found that interference from unpleasant pictures was attenuated for the mindfulness meditation training group only at post-test, and that this group also showed a significant reduction in their intensity ratings to the unpleasant pictures. This suggests that mindful self-awareness may play an important role in the exercise of EF in emotional contexts, via the reduction of emotional reactivity.

There is also promising evidence that mindfulness training can promote executive function in young children. In a pilot study by Johnson, Forston, and Zelazo (2013), children were randomly assigned to mindfulness meditation training or an active control condition in which children participated in active cognitive activities such as reading and singing. The mindfulness training consisted of ten 20-minute sessions occurring two times a week, using a variety of mindfulness exercises designed to promote self and body awareness. Children completed cognitive testing both prior to and after the training period. Significant improvements between pre- and post-test were found on tests of EF and theory of mind for the mindfulness training group only (Johnson et al., 2013).

In summary, research suggests that EF can be improved by targeting reflective processing in various ways, which in turn lends support to the idea that developmental increases in EF are a function of increases in the efficiency of iterative reprocessing (and hence, the capacity for reflection).

Potential for Training Reflection in Adolescents in the Strategic Pursuit of Goals

We propose that reflection-training strategies could be fruitfully combined with Implementation Intention and Mental Contrasting approaches in the facilitation of successful goal setting and striving in adolescents, and in ways that maximize the personalization of interventions for different ages and developmental levels. We noted that adolescents may benefit from reflection training that helps them to recognize relevant factors to be considered in planning the transformation of current reality into desired future, recognize conflicts among goals and plans, exercise flexibility in restructuring rules, and use more abstract cues to prime goal-related actions.

Indeed, one approach that would integrate reflection in strategies to promote adaptive rule use, would be to cue reflective processes via external verbal support during the mental contrasting and planning process. As in early childhood, verbal scaffolding can prompt more complex thought about a problem, and increase the possibility of more articulated plans that take into consideration various contingencies and unexpected but possible outcomes of plans. For example, if the goal is to increase the number of hours spent studying for a challenging class, adolescents might benefit from being asked to consider various potential obstacles to accomplishing this goal, and other goals and plans that might interfere with this one and then to specify the time of day at which this increased studying would likely take place. This process, insofar as it would prime relevant information that in turn can be used in the formulation of rules to guide behavior, would be expected to promote EF.

Likewise, in hot contexts in which adaptive goals are likely to run up against competing desires (like maintaining peer acceptance), making it more difficult to engage in reflection, adolescents would likely benefit from being prompted to consider in detail the various potential short and long-term consequences of various courses of action. For example, when confronted with the temptation to engage in a task that would interfere with the goal of studying (e.g., a request by a friend to play soccer after school), prompting prior reflection on the possibility of such temptations may allow this temptation more readily to be considered in the context of one’s study goals. Such cueing might lead one to pre-decide that if the opportunity to play soccer during the week arises, it is okay to play only if 10 hours of studying for the week have already been completed. Cued reflection might also be expected to facilitate spontaneous reflection on future occasions and in new domains of problem solving which in turn might be expected to improve the quality of advanced planning and, ultimately, the achievement of one's goals.

Mindfulness meditation training is also a promising approach to use with adolescents to promote reflective processes that can improve flexibility with respect to goal pursuit (Broderick, 2013). Mindfulness training exercises sustained reflective attention—it involves practicing reflection—as well as minimizing various obstacles to reflection, such as stress (Zelazo & Lyons, 2012), and for this reason may be expected to permit increased flexibility in modifying pre-established plans to achieve a particular outcome, or to enact plans in the face of a new cue. As discussed above, mindfulness training can also improve the regulation of emotion and physiological arousal (Ortner et al., 2007). Physiological arousal may interfere with slow, deliberative effortful thought processes because reflective processes are inhibited as attention is narrowed. By practicing mindfulness, adolescents may be better able to reduce emotional arousal when in hot contexts (e.g., experiencing peer pressure to act in a way that is discrepant with one's goals), which may in turn promote awareness of competing motivations and the consequences of different choices.

Reflection can also be encouraged through priming techniques that elicit abstract thought and representations, which in turn may permit broader and more adaptive thinking in the service of formulating and striving for goals. More specifically, adolescents may benefit from interventions that prime an abstract level of mental construal (of events, people, places and objects). Priming a spatiotemporally distanced perspective with respect to the self has been shown to improve self-regulation in adults (Fujita, Trope, Liberman, & Levin-Sagi, 2006). One might expect that adolescents who are primed to think at a more abstract level will be better able to engage in reflection when a particular problem arises. For example, one could prime adolescents to think of themselves at a time point in the future (e.g., a year from now), and then have them think of a particular goal they would like to achieve in the next year. Such priming may facilitate reflection about what it might take to achieve this goal, which in turn may lead to more effective plans and implementation intentions. Furthermore, thinking at a more abstract level might promote reflective processes that might lead to spontaneous generation of abstract cues to use in implementation intentions. For example, without much reflection, one might formulate the rule, ‘If it’s 4pm, then I will study’. However, a more adaptive formulation might be, ‘If the school day is over, then I will study’. The latter formulation is sufficiently abstract to avoid the goal derailment that may ensue if one’s day does not go as expected.

Similarly, Munakata, Snyder, and Chatham (2012) have argued that children’s improvement on EF tasks like the DCCS is a function of the capacity to proactively maintain robust, abstract representations in working memory. Research suggests that children who pass the DCCS are using more abstract representations of the stimuli in the rules that guide their sorting, inferred from their ability to apply these rules to novel stimuli (Kharitonova, Chien, Colunga, & Munakata, 2009). Suggestively, research has found that adolescents with lower activation in neural regions supporting the proactive maintenance of abstract representations perform more poorly on tasks assessing cognitive control than those with normal activity in those regions, and that lower activity predicted lower scores on self-report measures of self-control (Andrews-Hanna et al., 2011).

Interventions that promote the abstract construal of information in adolescence may prove beneficial to self-regulation, by promoting reflection and the tendency to formulate more thoughtful, adaptive plans. On the other hand, recent work suggests that abstract construals might interfere with self-regulation. For example, it has been found that high-level construals lead to more procrastination of goal pursuit than low-level construals (Gollwitzer, Wieber, Meyers, & McCrea, 2010). Thus, it may be that for abstract construals to be effective in promoting self-regulation they must be part of a hierarchical system of construals and rules, with the lowest levels in this system relating directly to the goal at hand, and we would expect that reflective processes would facilitate the formulation of such hierarchical systems of construals, which in turn would allow for navigation through levels of abstraction as needed to produce adaptive responding.

Conclusion

Adolescence is a challenging period of development during which it may be particularly difficult to formulate and achieve positive goals. Research on goal setting and striving has shown that training teens to use rules facilitates goal planning and achievement. We have suggested additional ways to enhance self-regulation in adolescents by using a developmental social cognitive neuroscience perspective and taking into account the developmental changes in reflection that occur during this period. Our brief review of research on the development of reflection and EF in early childhood yields the insight that interventions to promote reflection in adolescents should foster the high-level skill of iterative reprocessing, increasing the efficiency of the neural circuits that underlie this skill. Research on the role of reflection in self-regulation in adolescence is still in its early stages, but it is a promising area that has the potential to provide insight into the basic mechanisms of adolescent cognitive development, and also to support the creation of interventions to foster healthy adaptation.

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