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A Developmental Science Perspective on Vulnerability and Intervention for Youth Mental Health

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Abstract

This chapter explores the ways in which developmental science can shed light on salient issues within developmental epidemiology and intervention science. The highly replicated pattern of typical age of onset for different classes of mental disorders suggests that these epidemiological patterns might be a result of periods of development when certain processes are highly plastic and more sensitive to environmental input (i.e., sensitive periods). Understanding the particular adaptive goals of each stage of development can thus reveal mechanisms associated with the characteristic forms of vulnerability during each life phase. Puberty appears to be a salient example of a developmental process associated with a sensitive period for social learning as well as with the emergence of a range of mental disorders that are particularly associated with social cognitive symptoms (e.g., depressive disorders). Developmental science also has implications for precision intervention. Developmental moderation of intervention effectiveness is commonly observed, but a mechanistic understanding of the processes that underlie these effects has received relatively little research attention. Although the integration of insights from developmental science into our approaches to understanding and treating mental disorders across the life span is just emerging, the prospects for greater understanding and more effective interventions appear to be promising.

Introduction

Developmental science is the study of the patterns and processes of biological, cognitive, and behavioral change that occur as an organism is growing and

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maturing. Our central thesis is that understanding the adaptive tasks that characterize different phases of development, and therefore the kinds of learning for which organisms are primed during these periods, offers a unique window into the mechanisms that increase vulnerability for the emergence of disorders at specific phases of life. This understanding, in turn, has the potential to inform us about how to fit treatments to individuals by matching interventions more precisely to the specific capabilities and forms of plasticity that are associated with their stage of development (i.e., developmentally informed precision medicine).

One of the striking features of the developmental epidemiology of mental disorders, especially the patterns of typical age of onset associated with specific disorders, is the consistency with which these disorders emerge at specific stages of development across multiple data sets (Jones 2013). For example, Kessler et al. (2005) reported data from the National Comorbidity Survey Replication study, a nationally representative epidemiological survey of mental disorders in the United States, and found that the median age of onset for anxiety (age 11 yr) and impulse control (11 yr) disorders was much younger than that for substance use (20 yr) and mood (30 yr) disorders. Moreover, Kessler et al. (2005) reported that half of all lifetime cases for these disorders begin by age 14 yr, and three-quarters by age 24 yr. In a subsequent review of the literature on the age of onset of mental disorders, which focused on the WHO World Mental Health Surveys, Kessler and Wang (2008) reported a very similar set of findings. Specifically, they found that the median and interquartile (IQR) range of onset age is much earlier for phobias (7–14 yr, IQR: 4–20) and impulse control disorders (7–15 yr, IQR: 4–35) than for other anxiety disorders (25–53 yr, IQR: 15–75), mood disorders (25–45 yr, IQR: 17–65), and substance disorders (18–29 yr, IQR: 16–43). They noted that although less data exist for non-affective psychoses like schizophrenia, evidence suggests that the median age of onset for these disorders is in the range of the late teens through early twenties.

These findings demonstrate that not only does each of the major classes of mental disorders have a specific and somewhat unique pattern of typical age of onset, but that the majority of individuals with a mental disorder experience the onset of the illness in childhood (< 10 yr) or adolescence (10–19 yr), which are particularly dynamic developmental periods in the life span. Although anxiety disorders are sometimes reported as a homogeneous category, it is important to note that some fear-based anxiety disorders (e.g., phobias and separation anxiety) typically begin in childhood. By contrast, other anxiety disorders that are characterized by more cognitive symptoms (e.g., worry), such as panic disorder, generalized anxiety disorder, and posttraumatic stress disorder, typically emerge after the early teens (Kessler and Wang 2008). As noted above, non-affective psychoses like schizophrenia typically begin in late adolescence or the early twenties, with males having a somewhat earlier age of onset compared to females (Häfner et al. 1989). It is also noteworthy that disorders with

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childhood or adolescent onset tend to be more severe, are less likely to be detected and treated, and are more likely to be associated with comorbidity, especially if untreated (Paus et al. 2008). All of this serves to emphasize the critical importance of understanding not only the underlying developmental processes that place individuals at greater risk for specific disorders during specific phases of maturation, but also how this information might inform early intervention and prevention programs.

The Emergence of Disorders during Development: The Role of Sensitive Periods

Although the patterns of typical onset age for specific disorders, described above, are well known and have been highly replicated, they are perhaps so familiar that we may forget to ask why a particular pattern, and not some other one, is observed. It is our contention that the key to understanding this is to characterize the specific developmental processes associated with each stage of the life cycle. By doing so, one can understand the nature of the particular capacities that are plastic (i.e., undergoing active growth and thus are sensitive to insult) during that phase of development. This, in turn, may help explain why, in some vulnerable individuals, these developmental processes go awry and lead to psychopathology. One approach to this set of questions, used extensively in developmental biology to characterize such periods, is the concept of *sensitive periods*.

Over time, evolutionary influences have shaped each species' development in order to regulate the timing of different forms of learning. Sensitive periods for learning are timed when important information is available and most useful to the adaptive development of the organism (Fawcett and Frankenhuis 2015). For example, humans and laboratory research animals have been found to share similar early sensitive periods in sensory regions, such as in binocular vision where there is a critical balance in the input from two eyes (Hensch 2005a). Humans also experience multiple early sensitive periods during the acquisition of language (Doupe and Kuhl 1999; Werker and Hensch 2015). Despite these compelling examples of developmental sensitive periods, the nature and timing that may exist in human cognitive, affective, and social development are not fully understood, and this may be critical to understanding the developmental windows that enable specific forms of psychopathology to emerge.

Consistent with these ideas, Ernst Mayr (1982:48) emphasized the "teleonomic" or goal-directed aspect of development:

> A physiological process or a behavior that owes its goal directedness to the operation of a program can be designated as "teleonomic"….All the processes of individual development (ontogeny) as well as all seemingly goal-directed behaviors of individuals fall in this category, and are characterized by two components: they are guided by a program, and they depend on the existence of some endpoint

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> or goal that is foreseen in the program regulating the behavior….Each particular program is the result of natural selection and is constantly adjusted by the selective value of the achieved endpoint.

This approach suggests that we may be able to understand mental disorders as reflecting failures to achieve one or more of the goals of development (Costello and Angold 2016), which may provide a key to understanding why particular disorders are more likely to emerge during particular phases of life. This model, however, requires an understanding of which developmental goals are particularly salient at different developmental phases. Although there is no generally accepted taxonomy of such goals across human development, one compelling example by Sroufe and Rutter (1984) provides a series of developmental goals specific to phases of development:

- Age 0–1 yr: biological regulations, harmonious dyadic interaction, formation of an effective attachment relationship
- Age 1–2.5 yr: exploration, experimentation, and mastery of the object world (caregiver as secure base); individuation and autonomy; response to external control impulses
- Age 3–5 yr: flexible self-control, self-reliance, initiative, identification and gender concept; establishment of effective peer contacts (empathy)
- Age 6–12 yr: social understanding (equity, fairness), gender constancy, same-sex friendships, sense of "industry" (competence), school adjustment
- Age 13+ yr: "formal operations" (flexible perspective taking, "as-if" thinking), loyal friendships (same sex), beginning heterosexual relationships, independence from family, identity

Such a system has a number of potential implications for understanding the developmental epidemiology of psychopathology (Costello and Angold 2016). First, it suggests that if we want to understand the developmental vulnerability to, and prevention of, a particular disorder, we must understand the normal developmental processes involved in the emergence of a particular capacity. To understand the emergence and treatment of anxiety disorders, we need to characterize how organisms respond to threat as well as the various systems (i.e., affective, cognitive, social, and behavioral) that are most involved with regulating these challenges at different stages of development. For example, the emergence of fear-based anxiety disorders, such as phobia and separation anxiety disorders during early childhood, could be related to the developmental goals associated with exploration and mastery of the external world (i.e., discovering what is safe and what is dangerous) and the requirement of caregivers as a secure base to facilitate such exploration. The later emergence of worry-based anxiety disorders, such as generalized anxiety and social phobia (Kessler and Wang 2008), might be related to the later emergence of social understanding and formal operations; that is, the emergence of "if-then" thinking

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might be a prerequisite to the symptomatic processes of rumination and worry. Finally, the emergence of mood disorders, which involve prominent symptoms associated with social cognition (e.g., self-critical attitudes, concerns with one's social value), may be related to peripubertal developmental processes associated with social learning during the establishment of loyal friendships, sexual relationships, and personal identity (Allen and Badcock 2003).

Second, this developmental approach suggests that psychopathological conditions that present in various ways during different developmental stages may share similar underlying mechanisms. For example, anxious attachment in a one-year-old may be linked to the emotional liability in the same child at age five, as well as to an inability to form lasting intimate relationships during adulthood (Costello and Angold 2016). Accordingly, interventions designed to support secure attachments in infants may not only have benefits for anxiety in one-year-olds, but also prevent social dysfunction during adolescence and adulthood.

Puberty as an Example

Puberty appears to be a key inflection point in the developmental epidemiology of mental disorders, with a number of major mental disorders showing dramatic increases in incidence during the peri- and postpubertal period, including depressive disorders, eating disorders, and substance use disorders (Patton and Viner 2007). As such, to understand developmental psychopathology we need to understand the nature of the developmental processes that occur during puberty, and how this might influence developmental goals and sensitive periods of learning. Indeed, extensive cross-species work on puberty offers especially useful insights into the nature of the sensitive periods that occur during this phase of development, thus providing important evidence to support the proposition that puberty is a critical period of development for social learning in particular.

For example, human social learning during the pubertal transition may share some parallels with sensitive periods for the acquisition of song learning in songbirds (Dahl et al. 2018). Gonadal hormones are thought to regulate the neurobiology of song learning by altering both motor flexibility and the salience of social cues. Changes in salience are thought to ensure appropriate selection of the song to be copied (i.e., the correct species, time, and context) and selection of an appropriate mate (Bottjer and Johnson 1997; Marler et al. 1988; Matragrano et al. 2013). In mammals, frontal neocortical areas, which play a critical role in higher cognition, self-regulation, and social behaviors, develop late: from the time of pubertal milestones into early adulthood (Piekarski et al. 2017b). In laboratory mice, the onset of puberty has been found to alter frontal cortex neurobiology rapidly, changing inhibitory neurotransmission mechanisms previously identified as key regulators of sensitive periods in the neocortex (Piekarski et al. 2017a, b). Changes in

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frontal cortex inhibitory neurotransmission can also be connected to changes in learning, thus suggesting a causal link between puberty and adolescent shifts in social learning. Indeed, in rats, the adolescent period is characterized by social learning such as rough and tumble play and learning about sexual encounters. Interestingly, male rats need exposure to testosterone during adolescence to display rapid learning from sexual experience, and they do not recover this learning if testosterone is replaced in adulthood (Schulz and Sisk 2016). Thus, in rodents, as in birdsong, we see a repeated pattern whereby developmental signals (specifically, the pubertal rise in gonadal hormones) prime the brain's ability to learn during an adolescent sensitive period when the information is (a) available in the environment and (b) developmentally appropriate.

If comparable sensitive period processes occur in association with pubertal maturation in humans, this could inform developmental timing and targets for interventions. For instance, if pubertal hormones underpin distinct changes in social learning, leveraging these insights by designing interventions to target this window of opportunity could have large, positive effects on developmental trajectories. In fact, human studies have shown that the sharp rise in testosterone at the onset of puberty in human boys as well as girls is associated with shifts in social and affective information processing (Braams et al. 2015; Cardoos et al. 2017; Spielberg et al. 2014) and increased prioritization of social status feedback (Cardoos et al. 2017). In their review of decades of research into the behavioral effects of testosterone in animals and humans, Bos et al. (2012) concluded that testosterone increases the "motivation to gain social status." In humans, the process of earning status and prestige through prosocial actions may influence developmental trajectories in a manner that is separate from gaining status through aggressive dominance (Allen and Badcock 2003; Cheng et al. 2013). This may result in puberty being a sensitive period during which various experiences of earning prestige (e.g., through popularity, kindness, or aggression) may more powerfully influence learning, and thus ongoing trajectories of status-seeking behaviors (for good or ill), than at other stages of development (Dahl et al. 2018).

Implications for Intervention

Here we explore some of the implications of taking a developmental science perspective on psychopathology for intervention approaches. One of the key features evident in any intervention trial is the very significant variability in outcomes observed among participants. Consequently, there have been calls to understand the most salient moderators of intervention effects (e.g., Kraemer et al. 2002). Examining this issue has at least two major benefits: it facilitates precision medicine to ensure that treatments and interventions can be targeted to individuals who will benefit most (Collins and Varmus 2015), and it can help researchers to elucidate mechanisms of risk and disease.

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The types of moderators that may exist for intervention effects can include both individual (participant) characteristics and intervention program features, such as content, provider, and design (Stice et al. 2009). Our focus here is on individual participant factors. Further, we address issues relevant to psychosocial intervention, as they are likely to be most informed by models of sensitive periods for learning.

There is a range of other individual moderating factors that have been studied in the context of intervention studies with children and adolescents. For example, sex is one of the most studied individual moderators of intervention effects. In general, females appear to benefit more from intervention and prevention programs that target psychological processes and risk factors (Stice et al. 2009). However, sex is clearly a relatively coarse measure of individual differences and needs to be supplemented by approaches that allow a more precise and fine-grained matching of individuals to interventions. Other moderators of intervention effects include socioeconomic disadvantage (Chen and Miller 2013) and genetics (Musci et al. 2014). Research is beginning to identify ways in which interventions can be matched to groups of individuals most likely to benefit. However, despite the fact that one of the greatest sources of individual variability among children and youth is their varying degrees of maturation, developmental factors have received relatively little systematic investigation as moderators of treatment effects. An extensive literature addresses the general question of which interventions are appropriate for children, adolescents, and adults as broad (and very developmentally imprecise) categories. However, little of this research has framed this question in terms of specific developmental *processes* that might serve to match individuals with treatments specifically designed to match their developmental capacities and/or critical inflection points in plasticity. In a recently published review on the developmental demands of cognitive behavioral therapy for depression in children and adolescents, Garber et al. (2016:208) concluded that "further research is needed to clarify the relations between specific skills taught to children in therapy and various developmental abilities, to determine the adequacy of existing assessment tools for creating a developmental profile for children entering therapy, and to identify the most effective strategies for tailoring treatment to a child's specific developmental level in the relevant domains."

Development as a Moderator of Intervention Effects

It seems plausible that older children and adolescents may be able to understand and utilize some of the concepts presented in psychosocial intervention programs better than younger adolescents or children, especially those that rely on complex self-regulation or decision-making skills based on executive cognitive functions. Consistent with this, a meta-analysis has shown that age was a significant moderator of depression prevention programs for youth, with older

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age predicting greater effectiveness (Stice et al. 2009). Another meta-analysis of eating disorder prevention programs found similar results (Stice and Shaw 2004). There have also been some failures to observe age moderation effects in treatment studies. For example, grade level was found not to be a moderator of the effect of a mindfulness intervention on self-regulation skills in primary school children (Alfano et al. 2009; Gould et al. 2012). It is unclear, however, whether these failures resulted from substantive (i.e., developmental processes are less relevant to these interventions) or methodological (e.g., low power to detect such effects) issues. Nevertheless, these findings suggest that some interventions might show stronger developmental moderation than others.

Developmental measures other than chronological age have also been known to moderate intervention effects in some cases. As noted above, one particularly salient developmental process during early adolescence is puberty, which may offer a better measure of maturation during this phase of life than chronological age. Indeed, pubertal development has been observed to moderate intervention effects. For example, an intervention designed to improve body self-esteem was found to be more beneficial among students who had already begun puberty (Cousineau et al. 2010), suggesting that those who had already experienced the developmental processes addressed in the program were more able to benefit.

What is missing in all of these studies is a mechanistic understanding of precisely *why* and *how* developmental differences determine differential responses to intervention. To achieve this, we need to take a more in-depth approach to understanding how specific developmental processes influence sensitivity to these environmental inputs.

Moderating Intervention Effects: Platforms and Plasticity

There are various ways in which developmental differences might interact to potentiate intervention effects. Some developmental differences, for instance, may be associated with the emergence of cognitive or self-regulatory abilities that provide a necessary *platform* to benefit from specific intervention techniques. One example might be an intervention that requires social perspective taking, often used in interventions for interpersonal aggression (Chalmers and Townshend 1990). Abilities associated with mentalizing and theory of mind are required for social perspective taking, yet they show significant developmental change across childhood and adolescence (Dumontheil et al. 2010). Still, without these abilities, the necessary cognitive platform will not be in place and the individual will be unable to utilize fully the techniques presented in the intervention. Such developmental platforms act primarily as moderators of treatment effects.

Periods of developmental change also involve significant *neural plasticity*. Environmental exposure can have a significant impact on sensitive periods (discussed above) as the brain is particularly susceptible to specific kinds of input

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during this time (Fawcett and Frankenhuis 2015). These periods of heightened plasticity may also act as moderators of treatment effects, by increasing the effectiveness of treatment during particular phases of development. They may also point the way to salient mediators (or mechanisms) by which interventions have such effects, by influencing trajectories via their enhanced impact on neural or psychological development during windows of high plasticity.

Defining Development: Limitations of Chronological Age and the Need for Developmentally Precise Measures

Typically, chronological age is used to define an individual's developmental stage or maturation. However, age is always, at best, an imperfect measure of maturation, a fact that has been recognized within developmental research for some time (Wohlwill 1970). This is particularly the case during adolescence, when developmental processes such as puberty and physical maturation can markedly vary between individuals of the same chronological age, even more so than at other developmental stages (Ellis 2004; Mirwald et al. 2002).

We need to develop ways of quantifying maturation such that there is a strong link between the maturational process being measured and the characteristics that act as proximal moderators of intervention effects (i.e., developmental differences in how cognitive, affective, and self-regulatory processes influence the ability to learn and utilize skills that enhance the management of mental health symptoms and risk factors). This will provide a platform to understand more fully the ways in which developmental variability might influence the impact of interventions. Given the neurodevelopmental processes that occur during the second decade of life, and the likely links between neurodevelopment and the emergence of capacities that will moderate intervention effects (such as executive cognitive functions), examining brain development may be an especially propitious way to advance our understanding of these issues. Indeed, developing reliable neurocognitive markers of adolescent development would be a boon to developmental science more broadly, as it would provide an important complement to other non-age-based measures of maturation that could have wide application.

Adolescent Brain and Cognitive Development

Adolescence is a particularly dynamic period of brain development, second only to infancy in terms of the extent and significance of neural changes that occur: neurobiological changes are observed in brain structure, function, and connectivity (Dahl et al. 2018). Overall, these brain changes are hypothesized to underpin growth in adolescent capabilities to engage in higher-order cognitive functions, including cognitive control and the regulation of behavior and emotion (Steinberg 2005). These normative developmental processes are

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required to prepare the brain to respond to the demands of both adolescence and future adult life, but they may also increase vulnerability for risk behavior and psychopathology (Paus et al. 2008).

Many changes in cognitive processing that occur during adolescence have been well established in the literature, suggesting that as adolescents develop, they show improvements in a variety of cognitive domains, including learning, reasoning, information processing, and memory (Kuhn 2006). In particular, cognitive control capabilities, which facilitate self-regulation of thoughts, actions, and emotions, continue to develop throughout adolescence in parallel with brain changes (Kesek et al. 2008). Cognitive control consists of distinct component processes that appear to be primarily supported by somewhat different cortical regions and to have distinct developmental trajectories (Dosenbach et al. 2006, 2008). For example, although the greatest developmental improvements in response inhibition and interference control are typically observed prior to adolescence, improvements in flexibility, error monitoring, and the updating of working memory are more likely to occur throughout the second decade of life (Crone and Steinbeis 2017). Those functions which do continue to show significant developmental change during adolescence seem to rely especially on the capacity for abstract representation, a capacity that increases distinctly during adolescence (Dumontheil 2014). The capacity for abstract representation can relate to both temporal (e.g., long-term goals, past or future events) and relational (e.g., higher-order relationships between representations rather simple stimulus features) processes (Dumontheil 2014). These increases in abstract thought lead to improvements in deductive reasoning, information processing, and the capacity for abstract, planned, hypothetical, and multidimensional thinking.

Recent research on cognitive development during adolescence has focused on both cognitive and affective processing, particularly in terms of how these processes interact and influence each other in the context of adolescent decision making. The capacity for abstract representation as well as for affective engagement with such representations (Davey et al. 2008) increases the capacity for self-regulation of affect (e.g., the capacity to initiate new or alter ongoing emotional responses) to achieve a goal (Ochsner and Gross 2005). Indeed, such capacities may specifically rely on the ability to represent and affectively engage with a longer-term goal to regulate a prepotent, stimulus-driven affective response. Short-term stimulus-driven affective influences on cognitive processing (including decision making, risk taking, and judgment) significantly change over adolescence (Hartley and Somerville 2015). The social and emotional context for cognitive processing during adolescence may also include factors such as the presence of peers or the value of performing a task, which are hypothesized to influence the motivational salience of specific contexts and the extent to which cognitive processing is recruited (Johnson et al. 2009). There is also increasing evidence that some of these changes in cognitive and affective processing are

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linked to the onset of puberty (Crone and Dahl 2012), and that flexibility of the frontal cortical network may be greater in adolescence than in adulthood (Jolles and Crone 2012).

These changes in cognitive functioning may have adaptive qualities that are part of normative adolescent development, but may also confer vulnerability to psychopathology in some individuals. Flexibility of cognitive control may result in an improved ability to learn to navigate the increasingly complex social challenges that are part of adolescents' social worlds. In addition, the ability to shift focus in a highly motivated way could allow increases in learning, problem solving, and the use of creativity (Kleibeuker et al. 2016). Of particular relevance here, such emerging abilities may also determine the degree to which an individual can take advantage of new learning opportunities, including mental health-promoting interventions.

A New Approach to Understanding Individual Differences in Development: Quantifying the Maturation of Neural Systems

Recent attempts to quantify brain maturation have most often utilized functional connectivity measures of the whole brain, whereby connectivity is calculated by correlating fMRI measurements between brain regions while subjects are "at rest" and not engaged in completing specific tasks (Dosenbach et al. 2010). Such measures offer significant advantages in terms of quantifying neural maturation: the task-free nature of the approach increases their generalizability (especially across development), there are no practice effects (facilitating repeated measurement within individuals), and resting-state measures generally show good test–retest reliability (e.g., Choe et al. 2015). Dosenbach et al. (2010) used multivariate pattern analysis (MVPA) methods to develop an estimate of each participant's functional connectivity maturation level, which explained 55% of the variance in chronological age; the cingulo-opercular and frontoparietal control networks showed the greatest changes. The pattern of MVPA feature weights indicated that functional maturation was driven both by the segregation of nearby functional areas, via the weakening of short-range functional connections, and the integration of distant regions into broader functional networks, by strengthening of long-range functional connections. These findings have now been replicated with new advanced techniques (e.g., Fair et al. 2013) in image processing and analysis. Moreover, deviation from normative growth curves in these maturational patterns has been associated with attentional control problems in youth. This suggests that maturation of these networks may critically underlie the development of executive control and abstract reasoning during adolescence.

These changes also have structural analogs. Networks of myelinated fibers, as measured through diffusion tensor imaging (DTI), gradually mature from local, proximity-based connectivity patterns to a more distributed, integrative

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pattern (Vertes and Bullmore 2015): a developmental shift that has also been proposed to support higher cognitive functioning. In a recent study, Baum et al. (2017) applied network analytic techniques to DTI data from a large sample of participants aged 8–22 yr and found that white matter networks become increasingly modular during adolescent development, but that targeted strengthening of hub connections also facilitated more global network integration. Importantly, these neurodevelopmental changes in patterns of structural connectivity mediated improvements in executive functioning during childhood and adolescence (specifically measures of attention, working memory, and abstraction/flexibility). Other recent reports from this cohort have demonstrated that abnormal patterns of neurodevelopmental change in connectivity, both in terms of the pattern and timing of these changes, are associated with increased risk for psychopathology (Alnæs et al. 2018; Kaufmann et al. 2017).

In sum, both functional and structural measures support models of increasing integration and segregation of networks across development. Although the principal focus in studies of adolescent brain development has thus far been on age-related changes, findings such as peaks in gray matter density, which coincide with timing of puberty onset, suggest that neurodevelopmental patterns align better with pubertal changes than with chronological age (Blakemore et al. 2010).

Developmental Consequences of Brain Network Maturation and Moderation of Intervention Effects

To date, no studies have applied these network-based measures of brain maturation to understand differential responses to intervention effects. However, there is a small literature that has explored the phenotypic and cognitive correlates of these neurodevelopmental patterns. As noted above, the current literature on structural and functional change associated with brain maturation suggests a model of tighter "integration" of some regions into long-range networks over development, while short-range connections between other sets of regions are segregated into separate networks. Crone and Dahl (2012) have proposed that because these long-range connectivity patterns are still maturing, it is likely that some aspects of executive function may be less automatic and more flexible during adolescence. This results in greater vulnerability on attentional and decision-making tasks under high demands (as the ability to integrate control is less automatic) and enables adolescents to respond in novel and adaptive ways. Dumontheil (2014) has proposed that the rostral prefrontal cortex (PFC) supports self-generated, abstract thought processing, and that the ability to attend flexibly to and process abstract representations develops in adolescence. Moreover, rostral PFC activation becomes more specific to relational integration during development. This may suggest that adolescence is a crucial time of development during which specific learning (or training)

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experiences may actively sculpt final connectivity patterns in some of these long-range executive function networks (i.e., plasticity; discussed above). In other words, this may be a particularly important period for the beneficial neurodevelopmental effects of psychosocial interventions, especially those that enhance self-regulatory abilities.

Integrating Neurocognitive Development into Precision Prevention and Early Intervention

Most psychosocial interventions aimed at treating or preventing mental disorders involve some combination of psychoeducational, cognitive, and behavioral techniques. The capacity of an individual to implement these techniques effectively relies on many of the executive functions that are thought to develop during adolescence. For example, many intervention techniques rely on the following cognitive skills (Garber et al. 2016):

- Metacognition: identifying thoughts or differentiating situations, thoughts, and feelings
- Recognition that thoughts can change
- Identification of different kinds of helpful and unhelpful thoughts
- Reasoning abilities: recognizing relationships between thoughts and feelings
- Cognitive flexibility

In addition, interventions often rely on social skills (e.g., self-reflection, social perspective taking, resistance to peer influence) and emotion regulation, especially the capacity to resist a strong prepotent, stimulus-driven affective response in service of a longer-term, temporally distant, goal. Critically, many of these capacities rely on the ability to represent, process, and affectively engage with temporally distant or relational abstract thoughts (Dumontheil 2014). However, there has been a dearth of studies in intervention science that have specifically studied the way in which developmental processes can act as salient moderators of an individual's capacity to benefit from these interventions. This opportunity to conduct such studies is particularly salient during adolescence, when the development of executive functions (especially those that rely on abstract representation) is occurring in concert with dramatic neurobiological changes. Adolescence is a key period in life that should be targeted for prevention and early intervention. Given the emergence of new insights into cognitive development, along with new methods for estimating neurobiological maturation based on characterizing both the functional and structural aspect of the neural connectome, such research programs need to be prioritized in the future. Ultimately, insights gained from these will advance developmental science, cognitive science, and intervention science.

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Conclusion

Developmental science offers insight into salient issues within developmental epidemiology and intervention science, particularly early intervention and prevention approaches to mental health. It brings attention to the highly replicated pattern of typical age of onset for different classes of mental disorders and suggests that they should be interpreted in terms of the different patterns of vulnerability created by periods of development, when certain processes are highly plastic and more sensitive to environmental input. If we understand the particular adaptive goals of each developmental stage, we can generate plausible hypotheses about the underlying mechanisms associated with vulnerability to the mental disorders that show increased incidence during each stage of life.

Based on converging human and animal research into the effects of gonadal hormones on brain development and environmental sensitivity, we propose that puberty is a particularly sensitive period for social learning. A deeper understanding of the developmental process holds promise for precision intervention and may permit interventions to be matched to individuals who are most likely to benefit from them. Although developmental moderation of intervention effectiveness is commonly observed, these processes have received relatively little systematic attention as variables that can be used to tailor intervention to specific individuals. The usual methods of describing development and maturation in clinical settings (i.e., chronological age) are very imprecise, especially during adolescence. However, brain and cognitive sciences are rapidly developing alternative methods of conceptualization and measurement and may be able to advance our understanding of these issues. In sum, although we have just started to integrate insights from developmental science into an approach that looks at and treats mental disorders across the life span, our prospects for new learning and more effective interventions appear to be strong.

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