Adolescent Health Series: Adolescent Neurocognitive Development in Western and Sub-Saharan African Contexts

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Summary

The transitional period of adolescence has long been associated with physical, social and behavioural change. During this time, adolescents start to develop their own self-identity, make important life decisions, and acquire the necessary skills to successfully transition to adulthood. More recently, advances in brain imaging technology have enabled increased understanding of structural and functional changes in the human brain during this developmental period, and how they relate to social, emotional, motivational and cognitive development. The ability to integrate these developing cognitive processes in increasingly complex social contexts is a key aspect of mature decision-making, which has implications for adolescent health, educational, economic and social outcomes. Insights from the field of developmental cognitive neuroscience could increase our understanding of this influential stage of life, and thus inform potential interventions to promote adolescent health, a critical goal for global health research. Many social changes occur during adolescence and the social environment shapes both brain and cognitive development, and the decisions adolescents make. Thus, it is important to study adolescent neurocognitive development in socio-cultural context. Yet, despite evidence from Western studies that socio-cultural and economic factors impact on adolescent neurocognitive development, existing studies of adolescent neurocognitive development in SSA are relatively scarce. We summarise research findings from Western and SSA contexts, and highlight areas where research is lacking. Longitudinal studies from more diverse global samples will be needed to build a comprehensive model of adolescent development, that characterises both commonalities in developmental trajectories, as well as the way these can meaningfully differ between both individuals and contexts.

Introduction

Adolescence can be defined as the period of life between the biological changes of puberty and the individual attainment of a stable, independent role in society[1,2]. However, the timing of both pubertal onset and adult role transition vary both between and within cultures[3]. In response to this, it has recently been argued that a broader, more inclusive definition of adolescence, spanning the ages of 10 to 24 years, most accurately conceptualises contemporary global patterns of adolescent development[4]. Adolescents constitute approximately one third of the total population of sub-Saharan Africa (SSA), a region which is projected to have more adolescents than any other in the world by 2050[5]. Yet, there is very little existing research into brain and cognitive development among adolescents living in this region.

Globally, developmental research has historically largely focused on infancy and the early years[2], and SSA is no exception – much of what is known about neurocognitive development comes from studies of young children[6–12]. However, adolescence is a unique stage of life, characterised by substantial physical, behavioural, social and neurocognitive change relative to early childhood and adulthood. During this time, adolescents develop their self-identity and make important decisions which impact on their long-term health, economic, social and educational opportunities and outcomes[3,13]. Adolescence can be considered a sensitive period for social development, during which brain and behaviour become increasingly adapted to one's unique social environment and individuals show heightened sensitivity to developmentally relevant social experiences[1,14]. In adolescence, this manifests as a re-orientation towards peers[14,15], as individuals explore and develop their own socially-integrated self-identity and align their behaviour with the social norms of those they identify with[16–18]. Many of the changes occurring in adolescence, such as heightened sensitivity to social cues and interactions and increased exploration of novel environments, likely confer adaptive benefits to the development of independence and survival and are observed in both humans and adolescents of other species[19,20]. However, they can also confer vulnerability. Key aspects of adult health behaviour emerge or are intensified during adolescence, from exercise and nutritional habits[22], to engagement in health risks such as substance use and unsafe sex[13,22,23], and the majority of lifetime mental illness begins before the age of 25[24,25]. Thus, understanding this influential stage of life is a critical goal for global health research.

This review outlines key developmental changes in brain and cognitive development in human adolescence, and how this can increase our general understanding of adolescent behaviour and decision-making, in addition to potential applications for adolescent health in SSA. Given that adolescence is a period of social reorientation[14,26], it is important to study adolescent neurocognitive development within socio-cultural context[1,27]. However, existing studies of adolescent neurocognitive development in SSA are relatively scarce. We review key findings of extant research, and highlight areas where evidence is lacking. Where there is a paucity of existing research, we use relevant research from non-SSA populations to speculate on the impact of challenges faced by adolescents growing up in SSA on cognitive development. Caution should however be exercised when applying the findings from research conducted in high income, Western countries. We discuss these limitations, in addition to methodological and logistical challenges involved in studying adolescent neurocognitive development in SSA, a region with large socio-cultural, economic and environmental variation. Finally, we make some suggestions as to how taking a developmental cognitive neuroscientific perspective can increase our understanding of adolescent health behaviour,

and how these principles might be harnessed when designing interventions targeting adolescents' health and wellbeing.

Adolescent Neurocognitive Development

Structural Brain Development

The human brain undergoes substantial structural and functional reorganisation during adolescence. Although the overall volume of the brain does not change after late childhood, there is converging evidence that cortical white matter volume increases throughout childhood and adolescence and this increase continues until the thirties, while cortical grey matter volume shows concomitant decreases in volume during adolescence, before stabilising in the mid-twenties[28,29]. While the precise relationships between these structural changes and underlying biological mechanisms are still debated[30–32], they are consistent with histological evidence of continued cellular reorganisation during adolescence[33–35]. These neurodevelopmental processes, such as axonal growth, myelination and synaptic reorganisation, are thought to facilitate developmental changes in connectivity within and between brain regions, resulting in alterations in the way information is integrated throughout the brain[36,37]. One of the brain regions that has received considerable research focus is the prefrontal cortex (PFC), one of several areas of the brain that undergoes prolonged development throughout adolescence[34,38,39]. The PFC is involved in a wide range of cognitive processes, including social cognition, cognitive control and motivational-affective processing. These processes form the cognitive building blocks of our everyday behaviours: the ability to set and maintain goals, ignore distractions, empathise with others and regulate our emotions.

Social Cognitive Development

Adolescence is characterised by social change, in which social factors increase in salience and value[1,40]. Compared with children, adolescents form more complex and hierarchical peer relationships and are more sensitive to acceptance and rejection by their peers[41–44]. An adolescent's social world is thus often unstable and changeable, for example, it is only later in adolescence that friendships become more stable and characterised by reciprocity[45]. Furthermore, self-reported friendship quality predicts mental health resilience and well-being longitudinally in young people (14-24 years)[46], highlighting the importance of social functioning in this period of development.

Although the factors that underlie these social changes are likely to be multi-faceted, it is notable that adolescence is also a period of pronounced structural and functional development of the 'social brain'[47–49]. This refers to a network of brain areas, including dorsomedial regions of the PFC, that are associated with social cognitive abilities[49–51]. Social cognition encompasses a wide range of processes which enable us to understand and interact with one another, from face processing to more complex social inferential processes such as understanding others mental states and using the perspectives of others to guide our actions[51,52]. Thus, social cognitive abilities play a critical role in the successful negotiation of complex social interactions and decisions[53]. These abilities, and the brain networks that support them[48,49], continue to develop into early adulthood and occur in the context of parallel developments in other neurocognitive systems such as cognitive control and motivational-affective processing[47].

Development of Cognitive Control

Cognitive control can be defined as the ability to actively guide behaviour and involves the coordination of a heterogeneous set of sub-processes that focus attention on goal-relevant information, while inhibiting goal-irrelevant information[54–56]. Studies indicate continued maturation of the component processes that make up cognitive control throughout adolescence and into early adulthood, as well as a steady increase during this period in the ability to co-ordinate these processes to guide thoughts and actions in a goal-directed manner[57,58]. These sub-processes, such as inhibitory control, performance monitoring, attentional shifting, and working memory (WM) are supported by integrated brain networks including the dorsolateral PFC[59,60] and there is considerable evidence for developmental changes in PFC recruitment during cognitive control tasks over the course of adolescence[57,58].

Cognitive control processes can be engaged in the absence of socio-emotional, motivationally relevant information, or 'cold' contexts. However, many of the everyday scenarios in which cognitive control is employed are characterised by motivational-affectively salient, or 'hot' situations and outcomes[61]. Social interactions represent a key source of motivational-affective responses, particularly during adolescence: social cues can elicit robust emotional responses, and those around us can be a salient source of potential rewards and punishments[62–65]. Successful navigation of these 'hot' situations involves the integration of cognitive control with mechanisms of social cognition, emotional responsiveness and motivation and is facilitated by the extensive connectivity of the PFC with many other brain regions, including areas of the social brain network and sub-cortical brain structures such as the amygdala and striatum[40]. These regions are implicated in multiple, distinct neural circuits which show temporal variation in their maturational trajectories, both within and between circuits, and become increasingly integrated during development[14,40].

Emotional Regulation

Emotional regulation describes the monitoring, evaluation and modification of our emotional states, and involves both the explicit strategic regulation of emotional responses, and more automatic, implicit regulatory processes that operate largely outside of our awareness[66]. Despite conceptual differences, both types of emotional regulation processes involve a network of extensively interconnected brain regions, including the PFC, amygdala and striatum[67]. These connections facilitate both the top-down regulation of affective responses by cognitive control and the bottom-up modification or disruption of cognitive control processes by affective information[67], and show marked maturational changes during adolescence[68-70]. Experimental studies of emotional regulation in typically developing adolescents indicate continuing developmental improvements in both implicit and explicit regulation and it has been hypothesised adolescence may be an important period for the development of adaptive emotional regulation, a key predictor of mental health and socio-economic outcomes[66].

Value-Based Learning and Decision-Making

Adolescence is characterised by changes in learning and decision-making, including value-based decision making, in

which potentially rewarding or costly choices are made based on the perceived value and risk of the outcomes. Experimental studies suggest that different components of value based decision-making show different developmental trajectories[71]. Children as young as 8 are able to estimate risk probabilities and reward values on developmentally adapted tasks[72,73]. However, the ability to use this information to make advantageous choices in 'hot' contexts characterised by high levels of emotion, reward or arousal, shows a more protracted course of development[71]. Adolescents are more likely to take risks in pursuit of a potentially rewarding outcome with 'hot' risky decision-making paradigms, indicating a peak in risk-taking during adolescence[71,74]. Delay discounting (the tendency to prefer smaller, immediate rewards over larger but delayed rewards) has also been shown to decrease as a function of age during adolescence[75–78].

Obtaining a rewarding outcome elicits robust activation of dopaminergic regions, such as the striatum[79], and it has been hypothesised that developmental changes in the dopamine system during adolescence may result in heightened reward sensitivity[80]. Both cross-sectional and longitudinal neuroimaging studies have found that, compared with children and adults, adolescents show increased striatal reactivity when receiving rewards[81–86], and studies using risky decision-making paradigms are mostly consistent with the hypothesis that adolescents are biased to take risks due to heightened reward sensitivity[83,85,87,88].

Although adolescents are often stereotyped as prone to take risks that can result in harmful outcomes, such as substance use and dangerous driving, increases in reward sensitivity can also drive adaptive risk-taking, exploration and learning[89]. When outcomes are unknown, such as in changing or novel environments, taking risks can facilitate learning through the acquisition of new information about the world around us, which can be used by adolescents to inform future decision-making[90]. Computational studies of value-based learning and decision-making suggest that adolescence is characterised by reductions in sensitivity to negative feedback and increases in sensitivity to reward[68,91,92], which may contribute to the observed increase in reward-approach and subsequent learning behaviour[93]. For example, adolescents (12-16 years) have been shown to preferentially seek rewards rather than avoid punishments on a probabilistic learning task, whereas adults learned to seek and avoid both equally[94].

In addition to changes in reward and punishment sensitivity, there is also evidence that in some 'hot' contexts adolescents do not engage regulatory prefrontal regions to the same extent as adults[95–97]. However, we should not assume this characterises all instances of value-based decision making in adolescence. Studies suggest that heightened reward sensitivity in adolescence can result in an enhanced ability to flexibly up-regulate cognitive control in a goal-directed manner relative to children and adults[97–100], indicative of the complex relationship between motivational-affective processing and cognitive control. Indeed, in contexts in which exploration of novel environments is associated with opportunity, adolescents (16–17 years) exhibit more optimal behaviour and learning strategies than adults[101]. Some risk-taking behaviours are strategic in nature and may in fact be dependent on the ability to engage cognitive control processes to achieve one's goal, even in the face of potential loss, such as auditioning for a desired role in a play or standing up to a bully[102]. Furthermore, when considering the optimality or rationality of a decision, it is important to take into account not just the degree of risk involved, but also the existence of differences between what adults and adolescents ascribe relative value to[1,102].

Social Context

Many of the decisions that adolescents make are taken in social contexts and it has been proposed that the risk of social rejection may be weighted more strongly by adolescents than other risks (such as health or legal risks) and therefore that engaging in risk-taking behaviour may sometimes be seen as the rational choice[1,103]. Behavioural and neuroimaging studies indicate that social context, particularly the presence of peers, has a greater impact on adolescent behaviour, including risky decision-making, in comparison to adults[104–107]. Studies of social context in adolescence have largely focused on the detrimental impact of peer influence on experimental tasks involving risky and reward-related decisions[104,108,109]. However, social context can also have positive effects on adolescent behaviour, and studies indicate a facilitative effect of peers on feedback-learning[110], group decision-making[111] and engaging in prosocial behaviour[112,113]. We discuss the potential implications of this for adolescent health and wellbeing in the final section of this review.

Individual Differences in Adolescent Neurocognitive Development

Research has so far predominantly focused on characterising average neurocognitive development in adolescence. While this has been essential in furthering understanding of typical patterns of development, the precise timings and trajectories of structural and functional brain development, and how this relates to behaviour, show substantial and meaningful variation between individuals[114,115]. Understanding sources of individual variation, such as genetics, puberty hormones, socio-economic status, culture and exposure to environmental stressors, will be fundamental in developing a more nuanced understanding of adolescent neurocognitive development across contexts.

In addition to direct social contexts, such as the presence of peers, adolescent decision-making and behaviour also vary according to the context of our broader social environment. Societal expectations of adolescents differ greatly across cultures, as do definitions of behaviours that are considered high-risk or socially unacceptable and opportunities to engage in different types of risky behaviours[116].

An advantage of experimental assessments of value-based decision-making is that they can be used to assess the propensity to take risks, or learn from experience, in a controlled choice environment and thus can be a useful tool for cross-cultural research into the underlying mechanisms of risky decision-making. A study of adolescents from 11 different countries found that laboratory tasks yielded more consistent patterns of developmental effects across cultures than self-report measures of risk behaviours[116]. Despite the existence of variation between countries, there were also similarities which suggest that risk-taking tendencies peak in the late teenage years in young people growing up in both Western and Non-Western countries[116,117]. However, further work is needed to understand *how* cultural differences contribute to variation in developmental trajectories of risky behaviours.

Adolescence can be thought of as a period of learning and adaptation, in which neurocognitive networks develop and are moulded through reciprocal interactions between brain, body, behaviour, and the environment[118]. The brain requires environmental input to complete development, and it has been hypothesised that adolescence is a period for the 'biological embedding of culture', whereby sensitivity to the social environment promotes optimal

development according to the specifics of one's local context[119]. Given that SSA is characterised by marked variation in socio-cultural and economic environments both within and between countries, this should be taken into account when considering adolescent neurocognitive development and applying findings from Western studies to adolescents in SSA contexts[120]. Yet to date, very few studies have investigated the effects of culture on neurocognitive development[121].

In the next sections we discuss evidence on adolescent neurocognitive development in SSA and highlight areas in which evidence from other countries suggests future research may be relevant, before discussing some of the ongoing challenges faced when conducting research in this region.

Adolescent Neurocognitive Development in Sub-Saharan Africa

Challenges in Studying Cognitive Development in SSA

Most studies of adolescent cognitive development (including the research reviewed above) have been conducted in so-called WEIRD societies (Western, Educated, Industrialized, Rich, and Democratic)[122], which account for only 10 percent of the world's adolescents, limiting the generalizability of study results. However, investigating neurocognitive development in SSA often involves both logistical and methodological challenges, which may provide some insight into why there is limited research in this area.

The availability of MRI units is currently scarce or nonexistent across SSA[123], and therefore unsurprisingly so has been developmental neuroimaging research among adolescents in the region. A recent study, which used locally adapted neuroimaging to investigate neurocognitive development in a South African cohort of 2-3-year olds, found evidence of similar associations between the brain and cognition to those observed in studies in high-income countries[12]. However, to build a comprehensive and generalisable model of adolescent neurocognitive development, studies of adolescence from diverse global samples including SSA are needed. Neuroimaging studies can provide key insights into the development of neurobiological mechanisms underlying complex aspects of behaviour and increase our understanding of the developmental trajectories associated with risk and resilience outcomes. They also have the potential to improve the predictive utility of some behavioural assessments of cognition on future outcomes[124].

There is also a marked paucity of culturally appropriate and standardized measures of cognition among adolescents in SSA[125]. Yet, tasks developed in high-income countries might not be appropriate in an SSA context, challenging the validity of the results, particularly measures that yield standardised performance norms. Systematic differences between research settings can also result in differences in cognitive task performance that do not necessarily reflect cognitive function. Many tasks have been developed and validated to assess a given underlying cognitive construct in high-income settings. However, to yield a valid and accurate assessment, these tasks are often reliant on the availability of trained assessors and a distraction free environment, which might not be available in low-resource settings[126].

Cross-cultural studies using tasks developed in high-income countries have generally shown lower scores in cognitive tasks among African samples compared to Western samples[127–130]. Differences in language, culture, ethnicity, education and context can lead to several type of biases and affect the validity of measures, both within

and between countries. Given the linguistic and cultural diversity of SSA countries, this presents a challenge[131–134]. Furthermore, many cognitive tests require basic literacy and numeracy skills, and were developed with individuals who were familiar with test demands through school exposure. This can be a barrier for SSA, the region with the highest out-of-school rate across all age groups, where nearly nine of ten individuals between the ages of 6 and 14 do not meet minimum proficiency levels in reading and maths[135].

Despite these challenges, there is evidence to support the value and effectiveness of adapting and validating cognitive tasks for different cultural contexts. In the next section we discuss existing research into adolescent cognitive development in SSA, including studies which have successfully adapted cognitive tasks within SSA contexts, in addition to highlighting areas in which future research is needed.

Existing Research

Many adolescents in SSA are exposed to negative life experiences such as poverty, malnutrition, early life stress, and diseases such as HIV and malaria[136–138]. While a discussion of the effects of adversity is beyond the scope of this review, there are multiple, potentially interacting, mechanisms through which high levels of adversity might impact on neurocognitive development including, but not limited to, poor nutrition, lack of stimulating learning conditions and increased exposure to both physical and psychosocial environmental stressors[139–142]. Thus, the majority of studies of cognition in SSA to date have focused on childhood poverty and nutrition[6–12], and cognitive impairment as a result of disease[143–146].

One of the few longitudinal studies measuring cognitive development among adolescents in SSA is the Young Lives project, a longitudinal study of child poverty conducted in Ethiopia, India, Peru, and Vietnam (totalling 12,000 participants across all sites)[147]. These data were used to investigate the relationship between stunting, a delay in physical growth during childhood as a result of poverty, malnutrition and/or infectious diseases, and cognitive development in children aged 8 to 15 years[148]. Consistent with previous research, child growth was an important predictor of subsequent school outcomes[148]. However, some of the negative effects of stunting on cognition were partially reversible: 36% of children showing stunting at age 8 caught up in terms of growth with their peers by age 15, and those who caught up in physical growth had smaller deficits in cognitive scores than those who did not[148]. These results highlight the importance of nutrition for cognitive development in both the early years and adolescence.

While studies of the impact of exposure to high levels of environmental adversity on cognition are of crucial importance, there are few studies investigating adolescent neurocognitive development in larger community samples of young people, which is important to build a comprehensive picture of typical developmental trajectories in adolescents growing up in SSA contexts. The majority of existing studies of cognition in typically developing adolescents in SSA have focused on 'cold' aspects of cognition, such as fluid intelligence, academic abilities and aspects of cognitive control such as WM and inhibition. These studies are largely cross-sectional and typically have focused on the influence of factors such as education and family environment on cognition in children and early adolescents (5-14 years), or the adaptation of 'Western' cognitive tasks to SSA contexts. For example, Holding et al.

(2018) developed a cognitive test battery for use among children and adolescents (7–18 years) in three cultural settings (Bangladesh, Ghana, and Tanzania)[149]. The tasks, which assessed aspects of cognitive control such as WM and inhibition, were systematically adapted to the different cultural contexts — including heavy piloting of both the content and the administration[149]. Scores were similar across sites and instruments presented adequate psychometric properties. Similar results were found using culturally adapted cognitive tasks with a school-age sample in Zambia, Cameroon, South Africa, and the Democratic Republic of the Congo[127–130] and a recent study found that associations between different aspects of cognitive control in Nigerian adolescents (12-21 years) resembled those predicted by existing models of executive functions derived from Western studies[150].

These studies highlight the importance of adaptation and validation of cognitive tasks within cultures, and the value in doing so for assessments of 'cold' aspects of cognition. In contrast, very little is known about the development of socio-affective and motivational processing and the influence of 'hot' contexts on cognitive control and decision-making among adolescents in SSA. Extensive adaptation and validation will also be needed to create appropriate assessments of the development of these aspects of cognition. In addition to being essential in informing our understanding of typical adolescent socio-affective development in SSA, this research may be particularly relevant to understanding the effects of exposure to psychosocial stressors – such as socio-economic instability and inequality, sparse or unstable caregiving, abuse and violence – on adolescent cognition.

Given the high HIV burden in many SSA countries, many adolescents have suffered adversity during development including the death and illness of primary caregivers, reduced frequency and/or quality of caregiver interaction, and the impact of negative stigma of HIV status on the family and child[151,152]. Early life stress, including childhood trauma, exposure to violence and maternal deprivation can result in altered neurocognitive development of affective and motivational processing during adolescence[153,154]. These changes can impact on an individual's ability to navigate the developmental changes of adolescence and may create vulnerability to later mental health difficulties and associated negative outcomes such as poorer educational attainment and social functioning[155]. However, early adversity can also result in developmental alterations that may be adaptive in some adverse or unpredictable later environments or even represent neurocognitive markers of resilience[156–158]. Studies of socio-affective and motivational processing therefore have the potential to inform the development of preventative interventions that aim to reduce the impact of early adversity on neurocognitive development and promote adaptive changes which foster resilience during adolescence.

Implications of Adolescent Neurocognitive Development for Intervention Design

Increasing our understanding of adolescent neurocognitive development across contexts, may give insight as to why some adolescents are successful in making the transition to adulthood, while others experience difficulties. Adolescence may represent a period of heightened neural plasticity, during which the brain is particularly amenable to change and the effects of experience and intervention[159,160]. Evidence from both global and SSA contexts suggests that incorporating perspectives from developmental cognitive neuroscience can be used to inform the design and selection of interventions to promote adolescent health and wellbeing, and to help adolescents who may be

struggling as a result of earlier environmental adversity.

Considering the influence of socio-emotional and motivational context on adolescent learning and decision-making may be particularly effective in supporting adolescents in the safe transition to adult independence. As an example, Graduated Driver Licensing, in which young drivers build up their experience gradually with extended periods of supervision in high-risk situations, such as carrying same-aged passengers, has substantially reduced young driver casualties and crash rates in adopting Western countries[161]. Similarly, interventions encouraging adolescents to make decisions in 'cold' contexts that they will benefit from even in 'hot' contexts (such as pre-exposure prophylaxis and long-acting contraceptives) may be particularly successful[162,163]. Interventions that provide adolescents with the opportunity and support to engage in positive risk-taking, such as trying out for sports teams, or initiating new friendships may also be an effective way for adolescents to engage in exciting and novel experiences that also promote their wellbeing[164].

Traditional conceptualisations of risk behaviours tend to focus on health, legal or financial risks, with less consideration given to the implications of social risk, such as the risk of social rejection by one's peers and/or wider community[165]. Yet, interventions targeting risky health behaviours such as unsafe sex or binge drinking in adolescence will likely benefit from recognising the role social risk and social influence plays in adolescent decision-making and wellbeing[103]. While intervention research highlights the importance of avoiding or reducing situations in which high-risk behaviours such as substance misuse or criminal behaviour can be mutually reinforced through peer feedback[166–168], the positive effects of social context and positive peer influence on behaviour should not be overlooked[112,113,169–171]. Interventions that mitigate the social risk of peer ostracization and facilitate the creation and support of positive peer groups for adolescents may be particularly effective in promoting prosocial, healthy behaviour[172]. Adolescent's heightened sensitivity to peer influence can also be harnessed as a driver of positive behavioural change. 'Grassroots' interventions, in which socially connected adolescents are supported in developing and delivering interventions, enable adolescents to identify the key issues in their community (which may differ to those defined by adults) and aim to spread behavioural change through shifting social norms. This type of intervention has been effective in reducing bullying and smoking in high-income countries[173,174], although evidence from Indonesia highlights the importance of careful adaptation to context and local resources[175].

Approaches targeting the salience of adolescents' social environments have already shown success in reducing risky health behaviours and enhancing educational outcomes within SSA contexts. A large-scale study in Botswana evaluating the delivery of information about safe sex practices to adolescent women (12-16 years) found that the intervention reduced pregnancy when delivered by peer mentors but had no effect when delivered by older teachers[176]. Other studies found that exposure to inspiring, relatable positive role significantly increase students' school performance among adolescents in Madagascar (9-15 years)[177] and Uganda (15-20 years)[178]. The heightened sensitivity of adolescents to social approval and rejection may have important implications for interventions targeting young women's engagement in transactional sex, a key contributor to the HIV epidemic in SSA. Qualitative work suggests that young women living in rural South Africa (13-20 years) are aware of the risks associated with these relationships but may overlook these risks in the pursuit of consumer goods perceived as essential to their

sense of self-worth and social status[179,180]. Given that within this cohort low self-esteem was associated with increased engagement in transactional sex[181], interventions are needed which take into account the psychosocial needs of adolescents during this developmental period[182].

Exposure to adversity during early life can impact on later brain development and cognition during adolescence and influence an individuals' ability to achieve their full potential[6]. Lower cognitive ability is associated with a range of disadvantageous real-world outcomes[183–185], highlighting the need for effective interventions for adolescents who are struggling due to disease exposure and other environmental adversities. In addition to the relevance of such interventions for educational attainment, interventions may also have implications for adolescent health. A cohort study among adolescent/young adult women (18–25 years) in rural South Africa found that individuals scoring in the bottom quintile on tasks assessing attentional switching and WM were more likely to report engaging in risky sexual behaviour, such as unprotected sex, concurrent partners and transactional sex[186]. A study from Sweden suggested that WM training can be effective in ameliorating cognitive deficits in adolescents (14-15 years) born at extremely low birth weight with low cognitive ability[187]. Given evidence from Western samples that some aspects of complex cognition, such as relational reasoning, show greatest training benefits in late rather than early adolescence, adolescence may represent a window of opportunity for interventions targeting aspects of cold cognition that show protracted development during adolescence[188].

Adolescents growing up in adverse environments may also develop protective, automatic emotional responses, such as avoidance or aggression, that may not be adaptive in the different contexts they encounter in adolescence such as school and broader social settings which can negatively impact on subsequent socio-affective development[153,154]. While alterations in the processing of threatening or uncertain information may confer adaptive advantages in unpredictable, adverse environments, they may become maladaptive later in life, particularly if the environment becomes more stable and less adverse[155,156]. Interventions that support adolescents in the development of explicit emotional regulation strategies, such as reflecting on their automatic responses to affectively charged situations, and whether or not they are adaptive to their goals in different contexts, have been effective in reducing crime and school dropout rates in disadvantaged male youth in Chicago[189]. Neuroimaging studies have also indicated that childhood maltreatment is associated with reduced activation of reward processing systems during adolescence[154,190]. Given the adaptive role of developmental changes in reward processing in adolescence, alterations or disruption to these developmental trajectories may reduce learning and exploration during this phase of life and it has been hypothesised that a lack of a developmental increase in reward sensitivity during adolescence may be a mechanism through which early childhood adversity is predictive of later emerging depression[154,156]. If so, adolescence may represent a critical period for intervention for depression, particularly with interventions that target reward processing systems such as behavioural activation therapy[191].

Conclusion

Increasing our understanding of adolescent neurocognitive development, and how this varies within individuals over time, between individuals, and across cultures can provide insight into why adolescence is a period of elevated

health vulnerability, who may be most at risk, and how best to design effective, interventions. However, there is still a lot we do not know about adolescent cognitive development within an SSA context. Longitudinal studies from more diverse global samples will be needed to build a comprehensive model of adolescent development, that characterises both commonalities in developmental trajectories, as well as the way these can meaningfully differ between both individuals and contexts.

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