The effects of social deprivation on adolescent development and mental health

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Adolescence (the stage between 10 and 24 years) is a period of life characterised by heightened sensitivity to social stimuli and the increased need for peer interaction. The physical distancing measures mandated globally to contain the spread of COVID-19 are radically reducing adolescents' opportunities to engage in face-to-face social contact outside their household. In this interdisciplinary Viewpoint, we describe literature from a variety of domains that highlight how social deprivation in adolescence might have far-reaching consequences. Human studies have shown the importance of peer acceptance and peer influence in adolescence. Animal research has shown that social deprivation and isolation have unique effects on brain and behaviour in adolescence compared with other stages of life. However, the decrease in adolescent face-to-face contact might be less detrimental due to widespread access to digital forms of social interaction through technologies such as social media. The findings reviewed highlight how physical distancing might have a disproportionate effect on an age group for whom peer interaction is a vital aspect of development.

Introduction

Social interactions are proposed to be a basic human need, analogous to other fundamental needs such as food consumption or sleep.[1] Indeed, feeling insufficiently connected to others is associated with profound and lasting negative consequences on physical and mental health, even leading to increased mortality.[2] Current efforts to contain the spread of COVID-19 have required sudden and commonly mandated physical distancing, removing many regular sources of social connection from people's lives. Such measures are likely to have a substantial effect, not only on the economy and society, but also on individuals' mental health and wellbeing through factors such as reduced contact with other people. It is possible that the effects of such deprivation of social contact will extend beyond the period of physical distancing and might affect the population for years to come.

Key messages

- Physical distancing measures to contain the spread of COVID-19 have removed many sources of face-to-face social connection from people's lives, which might affect people's mental health, particularly in adolescence, a period of life characterised by a heightened need for peer interaction
- Animal research suggests there are unique effects of social isolation and social deprivation on brain and behaviour in adolescence; although the isolation in these studies is more extreme than the reduced social interaction associated with physical distancing, this literature suggests that adolescents might be particularly affected by deprivation of their social needs
- Adolescents' use of digital technologies and social media might mitigate some of the negative effects of physical distancing
- We call for an increased sensitivity during the COVID-19 response to the needs of adolescents, for whom peer interaction is a vital aspect of development

The negative effects of physical distancing and social deprivation might be particularly profound for adolescents (aged 10–24 years).[3] Adolescence represents a sensitive period for social interaction.[4] In this Viewpoint, we discuss evidence that human adolescents are hypersensitive to social stimuli and to the negative effects of social exclusion.[4] We review animal models that show extreme forms of social deprivation, including complete social isolation during adolescence, which have damaging effects on brain and behavioural development. This global crisis has, however, struck at a time when many adolescents are well positioned to mitigate some of these social shortfalls using digital means of connection.[5] This Viewpoint therefore synthesises interdisciplinary scientific findings relating to adolescent social processing, social isolation, and digital social behaviours. We also highlight how adolescents might be particularly affected by social deprivation, especially the reduction of peer contact, and how this must be taken into account when considering the long-term consequences of global COVID-19 prevention measures.

Adolescence is a sensitive period of social development

In parallel with the hormonal and biological changes associated with puberty, adolescence is a time of profound psychological and social transformation. During adolescence, the social world and the peer interactions it enables become increasingly important. Compared with children (aged <10 years), adolescents spend more time with peers than with their family and form more complex peer relationships.[6] The importance of obtaining peer social approval increases and peer influence is heightened in adolescence.[7–10] Indeed, adolescents are markedly more sensitive to peer acceptance, rejection, and approval than are children or adults.[11–13] This reorientation towards peers facilitates young

people's development into independent adults, enabling them to foster a more complete sense of social self-identity, at the same time as building stronger affiliations with their peer group.[14] Simultaneously, cognitive abilities such as self-referential processing,[15] executive control,[16] and mentalising, improve across adolescence, enabling young people to better understand other people's minds and take others' perspectives.[16] The development of high-level cognitive processes provides adolescents with the mental machinery to reflect on themselves and other people and to navigate social networks that start out as unstable and less reciprocal and gradually become more refined and reciprocal throughout adolescence.[17]

Indeed, adolescence can be considered a sensitive period for social development,[4] which might be partly dependent on the development of the social brain: the network of brain areas involved in social perception and cognition that allows us to understand others.[18] As with most regions within the human cortex, the structure of the social brain develops substantially throughout adolescence.[19] Multiple longitudinal MRI studies have shown that, across the cortex, the volume of grey matter, mostly consisting of cell bodies and synapses, declines from late childhood to the mid twenties,[20,21] whereas the volume of white matter, consisting of myelinated axons, gradually increases.[21] These macrostructural changes are thought to correspond to neurodevelopmental mechanisms at the microstructural level, including the myelination and growth of axons and synaptic reorganisation, which are partly dependent on environmental input and represent mechanisms of developmental neuroplasticity.[22,23] Thus, the heightened neuroplasticity that characterises early development[24] is proposed to continue into adolescence.[20,21,23] For healthy development, parental and caregiver input is a crucial component, especially during early development, whereas later in development the influence of peers becomes an additional important element of the social environment.[25]

Adolescence is also a period of heightened vulnerability to mental health problems, with 75% of adults who have ever had a mental health condition reporting that they first experienced symptoms before the age of 24.[26] There is evidence that problems with peer relationships, peer rejection, bullying, and loneliness are risk factors for the development of affective conditions such as depression in adolescence.[27,28] Conversely, high quality peer relationships appear to protect against mental health problems and strengthen adolescent resilience.[29] It follows then that widespread changes in the social environment, such as enforced physical distancing and reduced face-to-face social contact with peers, might have a substantial effect on brain and behavioural development during adolescence.

It is important to note, however, that physical distancing might not affect all adolescents in the same way. For example, adolescents who are living with high functioning families and who have positive relationships with parents or caregivers and siblings might be less affected by physical distancing than adolescents who do not have positive family relationships or who are living alone. Furthermore, as physical distancing rules vary by country, region, and across time, some face-to-face contact with non-household members might be permitted for certain adolescents. Nevertheless, many young people around the world currently have substantially fewer opportunities to interact face-to-face with peers in their social network, putting their social needs at risk of not being met at a crucial time of social development.

The effects of social deprivation on adolescent brain and behaviour: evidence from animal models

There is little research on the effects of social deprivation or isolation on human adolescent development or on adult humans in general. Several studies have focused on loneliness in humans and have reported a connection between self-reported loneliness and mental health problems.[30] However, such studies do not clearly establish whether loneliness results in mental illness or vice versa. Furthermore, human loneliness is not straightforward to study experimentally as loneliness is not a simple product of objective social deprivation: people can be alone without feeling lonely or feel lonely even in a crowd.[30] In contrast, there is a long history of animal research documenting the causal effects of social deprivation, including complete isolation, on brain and behavioural development during animal adolescence.[31] These animal models usually involve depriving animals of any form of social contact with their own species and studying changes in brain and behaviour both during and after social isolation. Although these experimental studies involve more extreme forms of social deprivation than the physical distancing experienced during COVID-19, the animal research literature provides valuable insights into the effects of depriving the developing animal of social contact during a sensitive period for social interaction.

Many animal studies have used rodents as their preferred animal model as these are innately social creatures and fare better in social rather than isolated housing.[32] This rodent research has shown that social isolation causes substantial changes in brain and behaviour,[31] especially if isolation occurs during development.[33,34] The effects of social isolation are considered to be twofold. First, social isolation is a stressor, and some of the effects of isolation can be attributed to general stress effects (engagement of the hypothalamus–pituitary–adrenal axis).[35,36] Second, social isolation also has effects that go beyond such general stress effects and can be attributed to the deprivation of stimuli crucial for the maintenance of neurobiological mechanisms and development.[33]

An advantage of rodent animal models such as mice and rats is that their development progresses through similar stages as human development.[37] To investigate the effects

of social deprivation or isolation on adolescent development, rodent studies have focused on the time period between weaning and adult maturity (corresponding to the time period from around postnatal days 21–60).[33,34,36,37] Similar to adolescent humans, after weaning, rodents show a strong orientation towards their peers.[38] These animals actively seek out peer interaction and these interactions are considered to be important social input for healthy development[39] and specifically for social learning.[34]

Behavioural effects of social deprivation in animal models

Many animal studies using rodents have investigated the effects of complete social isolation at different stages of development. Although the negative effects of social isolation in very early development are mainly linked to a lack of maternal care,[33,36] it is specifically interaction with peers that is important for adolescent animals.[39] On a behavioural level, even a brief duration (eg, 24 h) of isolation in adolescent rodents can cause increased anxiety,[40] hyperactivity,[41] and heightened sensitivity to social rewards,[42] which extends to the seeking of food or drug rewards, making these animals particularly prone to developing addictions.[43] Although reintroducing acutely isolated animals to social contact can alleviate some of the negative effects of short-term isolation, such as anxiety,[40] there are long-lasting negative consequences that are not easily remedied. For example, increased ethanol consumption in animals after social isolation persists even after the reintroduction to social housing.[44] When rodent adolescent isolation occurs chronically, over 1 week or longer, it has even more profound effects. Chronically isolated adolescent rodents (isolated throughout the whole adolescent period) have shown abnormal behaviours such as hyper-reactivity to stressful situations[45] and increased aggression.[46] Isolation-induced changes additionally occur for cognitive processes, such as learning and attention, and result in diminished performance on tasks that involve these processes. Particularly, isolation during adolescence results in cognitive flexibility deficits that impair reward learning,[47] reversal learning,[48] and attention shifting.[49]

Other studies have deprived animals of social contact with peers during their peak social play periods,[50] rather than complete isolation throughout adolescence. In most of these studies, animals were isolated from peers from around postnatal days 21 to 43, corresponding roughly to early adolescence (aged 10–13 years) and mid adolescence (aged 14–16 years) in humans.[34] Such studies show similar effects to those investigating isolation throughout the whole adolescent period, including increased anxiety-like behaviours, depression-like behaviours, and reward seeking, but impaired reward learning and habituation to novel stimuli.[36] Furthermore, increased aggression is also observed when rodents are raised with genetically modified conspecifics that show reduced social interaction,[51] suggesting that behavioural changes also occur under less extreme forms of social deprivation.

Brain effects of social deprivation in animal models

Complete social isolation in adolescent rodents evokes widespread structural and functional changes in the brain, most prominently in neuromodulatory dopamine and serotonin systems and particularly within cortical and striatal targets.[33,36,37] Thus, complete social deprivation during rodent adolescence affects brain development, mainly affecting motivation and reward processes.[33,36] Importantly, these effects are specific to isolation during rodent adolescence and do not occur to a similar extent when isolation occurs before or after adolescence.[33,36] More specifically, although some divergent effects have been observed, the most consistent findings report that dopamine release in reward regions such as the nucleus accumbens increases following adolescent isolation, but dopamine activity in the prefrontal cortex decreases.[33,36,37] These changes result in dysregulation of dopaminergic signalling in distinct brain structures responsible for processing salient stimuli.[52] Additional neurochemical changes include alterations to serotonin levels, with the direction of the effects differing between brain regions. For example, the prefrontal cortex shows increased serotonergic activity, whereas other brain areas, such as the hippocampus, show decreased activity. These alterations have been proposed to underlie observed behavioural changes such as increased anxiety and hyperactivity.[33,34] Even if not completely isolated, but instead deprived of peer contact by being reared solely with an adult animal, adolescent rodents show brain-level changes including reduced synaptic pruning in the prefrontal cortex.[53]

There are several studies that have investigated the effects of social deprivation at different stages of development in other species, such as non-human primates, birds, fish, sheep, and others. Many studies have investigated deprivation of peer contact in adult animals[54] and have found that, across species, deprivation of contact with peers resulted in negative behavioural and physiological effects, suggesting that the need for peer to peer contact is universal across social species.[55] Although much scarcer, research on the effects of social deprivation in adolescent non-human primates has shown effects in line with the rodent research: deprivation of contact with peers for 1–3 weeks results in anxiety-like behaviours and a reduction in cell proliferation and neurogenesis in the hippocampus (a brain region involved in learning and memory).[56]

Relating animal and human studies of isolation

In summary, social deprivation and isolation have substantial effects on adolescent animals, ranging from neurobiology to cognition and behaviour, which extend well beyond the period of isolation and can have long-term consequences. However, it remains unclear how well the social needs of rodents map onto the social needs of humans.[54] The social world of rodents differs in many ways from the complexity of human sociality, so

social deprivation might have differing effects between species. Most animal studies focus predominately on males, with female rodents included in only a few studies, and therefore do not represent the constellation of the human population. Furthermore, although the sequence of developmental stages is consistent between species, the different time intervals of development in rodents compared with humans open up additional questions about homology across species.

Comparable research on social deprivation in humans is scarce, but a small number of studies have investigated the effects of extreme forms of isolation like solitary confinement. They suggest that such isolation in prison leads to increased distress, depression, and aggression as well as increased prevalence of self harm in adults.[57] These detrimental effects are amplified in adolescent prisoners: one study showed that being younger than 19 years of age and assignment to solitary confinement were the two strongest predictors of self harm in prisoners.[58] However, the nature of these studies means that they relate to non-representative groups and are therefore difficult to interpret due to many confounding factors.

Beyond these extreme forms of isolation in non-representative groups, evidence on experimentally-induced acute social isolation in adult humans shows that isolation results in increased feelings of loneliness, craving for social contact, and decreased happiness.[59] In the human brain, isolation alters neural patterns in ways similar to food deprivation:[59] brain activity in the substantia nigra (the core of the brain's dopaminergic motivation centre) when people crave social contact after acute isolation mimics the activity exhibited there when they crave food after fasting. There is, therefore, evidence that at least some of the effects of social isolation observed in animal models can be extended to humans. However, more research is urgently needed to understand how social deprivation affects human development and mental health.

The animal studies reviewed suggest that the consequences of deprivation of social needs during adolescence can have negative effects resembling features of human neuropsychiatric disorders and on social cognitive development more broadly, due to lack of experiences for social learning. Specifically, it appears that it is particularly the lack of social interaction with peers that elicits behavioural and brain-level changes. The physical distancing measures that are currently in place across the globe in response to COVID-19 will probably reduce many adolescents' ability to fulfil their social needs. Although adolescents might still have contact with household members and with people beyond their home via virtual forms of communication, opportunities for face-to-face interaction with peers will be drastically reduced or eliminated. Although for some adolescents, social interactions at home might meet their social needs, physical distancing will challenge many teenagers' capacity to connect with peers. Research is therefore needed to understand whether the effects of social deprivation found in animal studies can be extended to apply to human adolescents. However, such research will need to investigate the possibility that virtual social connection might mitigate these effects.

Digital sources of social connection

Young people have been some of the first large-scale adopters of communicative digital technologies, such as social media and smartphones.[5,60] 69% of young British adolescents (aged 12–15 years)[61] and 97% of American adolescents (aged 13–17 years) have a social media profile.[62] The majority of US teenagers spend more than 4 h a day on social media sites[60] and almost half of them report that they are almost constantly engaging online.[62] Notably, income and education gaps between those who use smartphones and social media and those who do not are still substantial in both high-income and low-income economies. There is a 15% gap in smartphone ownership between lower-income and higher-income teenagers in the USA.[60] Moreover, 58% of Nigerians with secondary education or more have a social media account compared with 10% of Nigerians without secondary education.[5]

Although physical distancing measures would have stopped all adolescent peer contact except the landline phone and letter writing just 3 decades ago, active social contact can now be mediated by digital applications, whether that be social media, video chatting or conferencing, blogging, or online gaming.[61] Digitally-mediated interactions challenge our traditional conceptualisations of what socialising entails[63] as they can be asynchronous, click based, or audio–video reliant. These means of interaction raise the possibility that digitalised social contact can mitigate the potentially harmful effects of physical distancing in young people.

Adolescents routinely report using digital technologies for actively social means.[64] In particular, those aged 13–17 years indicate that technologies like social media make them feel more connected with their friends (81% of 743 respondents), help them interact with more diverse groups of people (69%), and allow them to access social support during tough times (68%).[62] Studies on adolescent social behaviour show that core components and qualities of adolescents' face-to-face interactions, including information disclosure, interactivity, social reward, and social support, are present when communicating online.[65] Online communication has been shown to remediate negative feelings after social exclusion.[66] Evidence for the ability of digital communication to mirror face-to-face contact effects extends to neuroimaging studies of human brain correlates of social processing. Due to the physical constraints of the MRI scanner, all neuroimaging studies focusing on the social brain and social cognition are limited to digitally-mediated social interactions instead of their face-to-face counterpart. Functional MRI studies have shown that experiencing partial components of

positive social interactions such as real time sharing of eye gaze,[67] hearing someone laugh after a telling a joke,[68] and observing videos from someone who has a shared intention,[69] activates neural reward systems in similar ways as do non-social rewards (eg, monetary rewards). Although these studies were done in adults, research in children and young adolescents (aged 8–12 years) similarly show that positive chat messages[70] evoke neural reward activity akin to activation resulting from monetary reward.

Digital interactions can be mediated via many different technologies ranging from interactive video games to social media. These can encourage a wide variety of activities ranging from popular pastimes such as connecting with friends or engaging with social media influencers[71] to less common activities such as accessing digital mental health interventions or exposure to harmful content (eg, online gambling and grooming).[72] Social media has especially become popular in the adolescent age group over the past decade.[61] To gauge the effect of social media on personal relationships and wellbeing, it is necessary to differentiate between its different uses.[73] Specifically, active uses of social media, for example engaging in directed communication (ie, messaging) or posting directly on another person's social media profile, have been shown to increase wellbeing[74] and help maintain personal relationships.[75] However, social media also allows for other activities less akin to the digital communication previously described (eg, passive uses such as scrolling through social media newsfeeds). These behaviours have routinely not been linked to positive outcomes.[76] There is initial experimental evidence that such passive uses could even negatively influence wellbeing, possibly by increasing social comparison and envy.[77] To understand how digital technologies affect adolescents who are physical distancing, we need to differentiate between connection promoting (ie, active and communicative) and non-connection promoting (ie, passive) uses of social media,[73] instead of focusing solely on the time spent using this medium.[78]

Furthermore, there is growing consensus that the consequences of social media use will be dependent on individual differences.[78] Some studies have supported the rich-get-richer view of online communication (ie, those who already have strong offline friendships might benefit most from digital interaction), whereas those with a liability to mental health issues might be more susceptible to the negative effects[78] (eg, those who have been victimised in person are more likely to be victimised or bullied online).[79]

It is difficult to parse the unique effects of social media and digital technology from the noisy background of adolescent life, making it challenging to give accurate and evidence-based recommendations in times of physical distancing that go further than promoting common sense approaches.[80] However, the existing evidence shows that certain aspects of digital communication can engender social connection and might, therefore, mitigate the consequences of physical distancing. Research should focus on this possibility.

Search strategy and selection criteria

We searched Scopus (which included PubMed and MEDLINE) for peer-reviewed articles between Jan 1, 2000, and Jan 4, 2020, on social behaviour in human adolescence, social isolation, and deprivation in adolescent animal models, which included measures of brain or behaviour and social media, adolescence, and mental health. We used the search terms "social isolation" or "social deprivation" and "adolescence"; all studies investigating behavioural or brain effects were included. We only searched for articles published in English or those translated into English.

Conclusion

With physical distancing being enforced by governments around the world, society is at the start of a period of intense and widespread reduction of face-to-face social contact. This Viewpoint highlights the urgent need to consider the wellbeing and development of adolescents. Adolescents are at a unique period in their lives when the social environment is important for crucial functions in brain development, self-concept construction, and mental health. Rodent studies show substantial and potentially long-term effects of social deprivation and isolation in adolescence on neurochemistry, structural brain development, and behaviours associated with mental health problems. Research on social isolation has almost entirely been carried out in animal models and little is known about how social deprivation affects human development. This Viewpoint considers the potential of social media and other digital technologies to mitigate the severity of social deprivation effects on human adolescents, but more research focused on this precise question is needed.

There are many questions that remain unanswered. It is unknown how long the physical distancing measures will be in place and whether or how they will affect development and mental health in the longer term. Even if physical distancing measures are temporary, several months of physical distancing represents a large proportion of a young person's life during a sensitive period of development, so it is possible that the effects will be more potent than for adults. Furthermore, there is little understanding on how the consequences of physical distancing compare with other stressors experienced by adolescents during the COVID-19 crisis, including economic pressures, uncertainty, and loss of public events marking key life stages and rites of passage. Adolescent physical distancing should therefore be given urgent consideration by policymakers and the opening of schools and other social environments should be a priority once physical distancing measures can be eased. There needs to be more information provided about the potential

merits (and harms) of digital connection and governments need to address the digital divide by supporting access to digital connection in families irrespective of income or location. Finally, there is an urgent need to understand the short-term and long-term effects of social deprivation and physical distancing, reduced face-to-face social interaction, and increased use of digital means of connection, on human adolescent development and mental health.

Contributors
All the authors contributed equally to this manuscript.

Declaration of interests
We declare no competing interests.

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References

1 Baumeister RF, Leary MR. The need to belong: desire for interpersonal attachments as a fundamental human motivation. *Psychol Bull* 1995; **117:** 497–529.
2 Hawkley LC, Cacioppo JT. Loneliness matters: a theoretical and empirical review of consequences and mechanisms. *Ann Behav Med* 2010; **40:** 218–27.
3 Sawyer SM, Azzopardi PS, Wickremarathne D, Patton GC. The age of adolescence. *Lancet Child Adolesc Health* 2018; **2:** 223–28.
4 Blakemore S-J, Mills KL. Is adolescence a sensitive period for sociocultural processing? *Annu Rev Psychol* 2014; **65:** 187–207.
5 Pew Research Center. Smartphone ownership is growing rapidly around the world, but not always equally (2019). https://www.pewresearch.org/global/2019/02/05/smartphone-ownership-is-growing-rapidly-around-the-world-but-not-always-equally/ (accessed June 1, 2020).
6 Lam CB, McHale SM, Crouter AC. Time with peers from middle childhood to late adolescence: developmental course and adjustment correlates. *Child Dev* 2014; **85:** 1677–93.
7 De Goede IHA, Branje SJT, Delsing MJMH, Meeus WHJ. Linkages over time between adolescents' relationships with parents and friends. *J Youth Adolesc* 2009; **38:** 1304–15.
8 Albert D, Chein J, Steinberg L. Peer influences on adolescent decision making. *Curr Dir Psychol Sci* 2013; **22:** 114–20.
9 Knoll LJ, Magis-Weinberg L, Speekenbrink M, Blakemore S-J. Social influence on risk perception during adolescence. *Psychol Sci* 2015; **26:** 583–92.
10 Foulkes L, Leung JT, Fuhrmann D, Knoll LJ, Blakemore S-J. Age differences in the prosocial influence effect. *Dev Sci* 2018; **21:** e12666.
11 Sebastian CL, Tan GCY, Roiser JP, Viding E, Dumontheil I, Blakemore S-J. Developmental influences on the neural bases of responses to social rejection: implications of social neuroscience for education. *Neuroimage* 2011; **57:** 686–94.
12 Somerville LH. Special issue on the teenage brain: Sensitivity to social evaluation. *Curr Dir Psychol Sci* 2013; **22:** 121–27.
13 Foulkes L, Blakemore SJ. Is there heightened sensitivity to social reward in adolescence? *Curr Opin Neurobiol* 2016; **40:** 81–85.
14 Pfeifer JH, Berkman ET. The Development of self and identity in adolescence: neural evidence and implications for a value-based choice perspective on motivated behavior. *Child Dev Perspect* 2018; **12:** 158–64.
15 Van der Aar LPE, Peters S, Crone EA. The development of self-views across adolescence: investigating self-descriptions with and without social comparison using a novel experimental paradigm. *Cogn Dev* 2018; **48:** 256–70.
16 Dumontheil I, Apperly IA, Blakemore S-J. Online usage of theory of mind continues to develop in late adolescence. *Dev Sci* 2010; **13:** 331–38.
17 Burnett Heyes S, Jih Y-R, Block P, Hiu C-F, Holmes EA, Lau JYF. Relationship reciprocation modulates resource allocation in adolescent social networks: developmental effects. *Child Dev* 2015; **86:** 1489–506.
18 Frith CD, Frith U. Social cognition in humans. *Curr Biol* 2007; **17:** R724–32.
19 Mills KL, Lalonde F, Clasen LS, Giedd JN, Blakemore SJ. Developmental changes in the structure of the social brain in late childhood and adolescence. *Soc Cogn Affect Neurosci* 2014; **9:** 123–31.
20 Tamnes CK, Herting MM, Goddings AL, et al. Development of the cerebral cortex across adolescence: a multisample study of inter-related longitudinal changes in cortical volume, surface area, and thickness. *J Neurosci* 2017; **37:** 3402–12.
21 Mills KL, Goddings A-L, Herting MM, et al. Structural brain development between childhood and adulthood: Convergence across four longitudinal samples. *Neuroimage* 2016; **141:** 273–81.
22 Yakovlev PL, Lecours AR. The myelogenetic cycles of regional maturation of the brain. In: Minkowski A, eds. Regional development of the brain in early life. Oxford: Blackwell, 1967: 3–70.
23 Petanjek Z, Judaš M, Šimic G, et al. Extraordinary neoteny of synaptic spines in the human prefrontal cortex. *Proc Natl Acad Sci USA* 2011; **108:** 13281–86.
24 Hensch TK. Critical period plasticity in local cortical circuits. *Nat Rev Neurosci* 2005; **6:** 877–88.
25 Nelson EE, Jarcho JM, Guyer AE. Social re-orientation and brain development: An expanded and updated view. *Dev Cogn Neurosci* 2016; **17:** 118–27.
26 Kessler RC, Petukhova M, Sampson NA, Zaslavsky AM, Wittchen H-U. Twelve-month and lifetime prevalence and lifetime morbid risk of anxiety and mood disorders in the United States. *Int J Methods Psychiatr Res* 2012; **21:** 169–84.
27 Arseneault L. Annual research review: the persistent and pervasive impact of being bullied in childhood and adolescence: implications for policy and practice. *J Child Psychol Psychiatry* 2018; **59:** 405–21.
28 Platt B, Cohen Kadosh K, Lau JYF. The role of peer rejection in adolescent depression. *Depress Anxiety* 2013; **30:** 809–21.
29 van Harmelen A-L, Kievit RA, Ioannidis K, et al. Adolescent friendships predict later resilient functioning across psychosocial domains in a healthy community cohort. *Psychol Med* 2017; **47:** 2312–22.
30 Cacioppo JT, Hawkley LC, Thisted RA. Perceived social isolation makes me sad: 5-year cross-lagged analyses of loneliness and depressive symptomatology in the Chicago Health, Aging, and Social Relations Study. *Psychol Aging* 2010; **25:** 453–63.
31 Matthews GA, Tye KM. Neural mechanisms of social homeostasis. *Ann N Y Acad Sci* 2019; **1457:** 5–25.
32 Wills GD, Wesley AL, Moore FR, Sisemore DA. Social interactions among rodent conspecifics: a review of experimental paradigms. *Neurosci Biobehav Rev* 1983; **7:** 315–23.
33 Hall FS. Social deprivation of neonatal, adolescent, and adult rats has distinct neurochemical and behavioral consequences. *Crit Rev Neurobiol* 1998; **12:** 129–62.
34 Burke AR, McCormick CM, Pellis SM, Lukkes JL. Impact of adolescent social experiences on behavior and neural circuits implicated in mental illnesses. *Neurosci Biobehav Rev* 2017; **76:** 280–300.
35 Chen Y, Baram TZ. Toward understanding how early-life stress reprograms cognitive and emotional brain networks. *Neuropsychopharmacology* 2016; **41:** 197–206.
36 Novick AM, Levandowski ML, Laumann LE, Philip NS, Price LH, Tyrka AR. The effects of early life stress on reward processing. *J Psychiatr Res* 2018; **101:** 80–103.
37 Lukkes JL, Watt MJ, Lowry CA, Forster GL. Consequences of post-weaning social isolation on anxiety behavior and related neural circuits in rodents. *Front Behav Neurosci* 2009; **3:** 18.
38 Vanderschuren LJMJ, Achterberg EJM, Trezza V. The neurobiology of social play and its rewarding value in rats. *Neurosci Biobehav Rev* 2016; **70:** 86–105.
39 Panksepp J. The ontogeny of play in rats. *Dev Psychobiol* 1981; **14:** 327–32.
40 Maisonnette S, Morato S, Brandão ML. Role of resocialization and of 5-HT1A receptor activation on the anxiogenic effects induced by isolation in the elevated plus-maze test. *Physiol Behav* 1993; **54:** 753–58.

41 Morley BJ, Worsham E. The effects of prolonged handling, scopolamine, and physostigmine on the activity of isolated and socially reared rats. *Physiol Psychol* 1978; **6:** 83–88.

42 Ikemoto S, Panksepp J. The effects of early social isolation on the motivation for social play in juvenile rats. *Dev Psychobiol* 1992; **25:** 261–74.

43 McCool BA, Chappell AM. Early social isolation in male Long-Evans rats alters both appetitive and consummatory behaviors expressed during operant ethanol self-administration. *Alcohol Clin Exp Res* 2009; **33:** 273–82.

44 Wolffgramm J, Heyne A. Social behavior, dominance, and social deprivation of rats determine drug choice. *Pharmacol Biochem Behav* 1991; **38:** 389–99.

45 Heidbreder CA, Weiss IC, Domeney AM, et al. Behavioral, neurochemical and endocrinological characterization of the early social isolation syndrome. *Neuroscience* 2000; **100:** 749–68.

46 St Popova J, Petkov VV. Changes in 5-HT1 receptors in different brain structures of rats with isolation syndrome. *Gen Pharmacol* 1990; **21:** 223–25.

47 Robbins TW. Neurobehavioural sequelae of social deprivation in rodents revisited: Modelling social adversity for developmental neuropsychiatric disorders. *J Psychopharmacol* 2016; **30:** 1082–89.

48 Amitai N, Young JW, Higa K, Sharp RF, Geyer MA, Powell SB. Isolation rearing effects on probabilistic learning and cognitive flexibility in rats. *Cogn Affect Behav Neurosci* 2014; **14:** 388–406.

49 Schrijver NC, Würbel H. Early social deprivation disrupts attentional, but not affective, shifts in rats. *Behav Neurosci* 2001; **115:** 437–42.

50 Vanderschuren LJMJ, Trezza V. The neurobiology of childhood. Springer, 2013: 189–212.

51 Stark R, Pellis SM. Male Long Evans rats reared with a Fischer-344 peer during the juvenile period show deficits in social competency: a role for play. *Int J Play* 2020; published online Feb 11. DOI:10.1080/21594937.2020.1720142.

52 Del Arco A, Mora F. Prefrontal cortex-nucleus accumbens interaction: in vivo modulation by dopamine and glutamate in the prefrontal cortex. *Pharmacol Biochem Behav* 2008; **90:** 226–35.

53 Bell HC, Pellis SM, Kolb B. Juvenile peer play experience and the development of the orbitofrontal and medial prefrontal cortices. *Behav Brain Res* 2010; **207:** 7–13.

54 Tomova L, Tye K, Saxe R. The neuroscience of unmet social needs. *Soc Neurosci* 2019; **20:** 1–11.

55 Petrovich SB, Gewirtz JL. The attachment learning process and its relation to cultural and biological evolution: proximate and ultimate considerations. In: Reite M, eds. The psychobiology of attachment and separation. Orlando, FL: Academic Press, 1985: 259–91.

56 Cinini SM, Barnabe GF, Galvão-Coelho N, et al. Social isolation disrupts hippocampal neurogenesis in young non-human primates. *Front Neurosci* 2014; **8:** 45.

57 Haney C. "Supermax" Confinement. *Crime Delinq* 2003; **49:** 124–56.

58 Kaba F, Lewis A, Glowa-Kollisch S, et al. Solitary confinement and risk of self-harm among jail inmates. *Am J Public Health* 2014; **104:** 442–47.

59 Tomova L, Wang K, Thompson T, et al. The need to connect: acute social isolation causes neural craving responses similar to hunger. *bioRxiv* 2020; published online March 26. DOI:10.1101/2020.03.25.006643 (preprint).

60 Rideout V, Robb M. The common sense census: media use by tweens and teens. https://www.commonsensemedia.org/research/the-common-sense-census-media-use-by-tweens-and-teens-2019 (accessed June 1, 2020).

61 Ofcom. Children and parents: media use and attitudes report 2018. 2019. https://www.ofcom.org.uk/__data/assets/pdf_file/0024/134907/children-and-parents-media-use-and-attitudes-2018.pdf (accessed June 1, 2020).

62 Pew Research Center. Teens' social media habits and experiences (2018). https://www.pewresearch.org/internet/2018/11/28/teens-social-media-habits-and-experiences/ (accessed June 1, 2020).

63 Dunbar RIM. Do online social media cut through the constraints that limit the size of offline social networks? *R Soc Open Sci* 2016; **3:** 150292.

64 Barker V. Older adolescents' motivations for social network site use: the influence of gender, group identity, and collective self-esteem. *Cyberpsychol Behav* 2009; **12:** 209–13.

65 Yau JC, Reich SM. Are the qualities of adolescents' offline friendships present in digital interactions? *Adolesc Res Rev* 2018; **3:** 339–55.

66 Knowles ML, Haycock N, Shaikh I. Does Facebook magnify or mitigate threats to belonging? *Soc Psychol (Gott)* 2015; **46:** 313–24.

67 Pfeiffer UJ, Schilbach L, Timmermans B, et al. Why we interact: on the functional role of the striatum in the subjective experience of social interaction. *Neuroimage* 2014; **101:** 124–37.

68 Sumiya M, Koike T, Okazaki S, Kitada R, Sadato N. Brain networks of social action-outcome contingency: the role of the ventral striatum in integrating signals from the sensory cortex and medial prefrontal cortex. *Neurosci Res* 2017; **123:** 43–54.

69 Eskenazi T, Rueschemeyer SA, de Lange FP, Knoblich G, Sebanz N. Neural correlates of observing joint actions with shared intentions. *Cortex* 2015; **70:** 90–100.

70 Alkire D, Levitas D, Warnell KR, Redcay E. Social interaction recruits mentalizing and reward systems in middle childhood. *Hum Brain Mapp* 2018; **39:** 3928–42.

71 Andrews JL, Foulkes L, Blakemore S-J. Peer Influence in adolescence: public-health implications for COVID-19. *Trends Cogn Sci* 2020; published online May 8. DOI:10.1016/j.tics.2020.05.001.

72 Grant JI. COVID-19: protecting children from online abuse. 2020. https://www.esafety.gov.au/about-us/blog/covid-19-protecting-children-online-abuse (accessed June 1, 2020).

73 Clark JL, Algoe SB, Green MC. Social network sites and well-being: the role of social connection. *Curr Dir Psychol Sci* 2018; **27:** 32–37.

74 Burke M, Marlow C, Lento T. Social network activity and social well-being. CHI'10: Proceedings of the SIGCHI conference on human factors in computing systems. Atlanta, GA: ACM Press, 2010: 1909–12.

75 Ellison N, Vitak J, Gray R, Lampe C. Cultivating social resources on social network sites: Facebook relationship maintenance behaviors and their role in social capital processes. *J Comput Commun* 2014; **19:** 855–70.

76 Burke M, Kraut RE. The relationship between Facebook Use and well-being depends on communication type and tie strength. *J Comput Commun* 2016; **21:** 265–81.

77 Verduyn P, Ybarra O, Résibois M, Jonides J, Kross E. Do social network sites enhance or undermine subjective well-being? A critical review. *Soc Issues Policy Rev* 2017; **11:** 274–302.

78 Odgers CL, Jensen MR. Annual research review: adolescent mental health in the digital age: facts, fears, and future directions. *J Child Psychol Psychiatry Allied Discip* 2020; **61:** 336–48.

79 Przybylski AK, Bowes L. Cyberbullying and adolescent well-being in England: a population-based cross-sectional study. *Lancet Child Adolesc Health* 2017; **1:** 19–26.

80 Hawkes N. CMO report is unable to shed light on impact of screen time and social media on children's health. *BMJ* 2019; **364:** l643.