Review article

Mechanisms linking social media use to adolescent mental health vulnerability

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Abstract

Research linking social media use and adolescent mental health has produced mixed and inconsistent findings and little translational evidence, despite pressure to deliver concrete recommendations for families, schools and policymakers. At the same time, it is widely recognized that developmental changes in behaviour, cognition and neurobiology predispose adolescents to developing socio-emotional disorders. In this Review, we argue that such developmental changes would be a fruitful focus for social media research. Specifically, we review mechanisms by which social media could amplify the developmental changes that increase adolescents' mental health vulnerability. These mechanisms include changes to behaviour, such as sharing risky content and self-presentation, and changes to cognition, such as modifications in self-concept, social comparison, responsiveness to social feedback and experiences of social exclusion. We also consider neurobiological mechanisms that heighten stress sensitivity and modify reward processing. By focusing on mechanisms by which social media might interact with developmental changes to increase mental health risks, our Review equips researchers with a toolkit of key digital affordances that enables theorizing and studying technology effects despite an ever-changing social media landscape.

Sections

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Introduction

Adolescence is a period marked by profound neurobiological, behavioural and environmental changes that facilitate the transition from familial dependence to independent membership in society[1,2]. This critical developmental stage is also characterized by diminished well-being and increased vulnerability to the onset of mental health conditions[3-5], particularly socio-emotional disorders such as depression, and eating disorders[4,6] (Fig. 1). Notable symptoms of socio-emotional disorders include heightened negative affect, mood dysregulation and an increased focus on distress or challenges concerning interpersonal relationships, including heightened sensitivity to peers or perceptions of others[6]. Although some risk factors for socio-emotional disorders do not necessarily occur in adolescence (including genetic predispositions, adverse childhood experiences and poverty[7-9]), the unique developmental characteristics of this period of life can interact with pre-existing vulnerabilities, increasing the risk of disorder onset[10].

Over the past decade, declines in adolescent mental health have become a great concern[11,12]. The prevalence of socio-emotional disorders has increased in the adolescent age range (10–24 years[2])[13-21], leading to mounting pressures on child and adolescent mental health services[16,21,22]. This increase has not been as pronounced among other age groups when compared with adolescents[20,22,23] (measured in ref. 20, ref. 22 and ref. 23 as age 12–25 years, 12–20 years and 18–25 years, respectively), even if some studies have found increases across the entire lifespan[24,25]. Although these trends might not be generalizable across the world[26] or to subclinical indicators of distress[15], similar trends have been found in a range of countries[27]. Declines in adolescent mental health, especially socio-emotional problems, are consistent across datasets and researchers have argued that they are not solely driven by changes in social attitudes, stigma or reporting of distress[28,29].

Concurrently, adolescents' lives have become increasingly digital, with most young people using social media platforms throughout the day[30]. Ninety-five per cent of UK adolescents aged 15 years use social media[31], and 50% of US adolescents aged 13–17 years report being almost constantly online[32]. The social media environment impacts adolescent and adult life across many domains (for example, by enabling social communication or changing the way news is accessed) and influences individuals, dyads and larger social systems[33-36]. Because social media is inherently social and relational[37], it potentially overlaps and interacts with the developmental changes that make adolescents vulnerable to the onset of mental health problems[38,39] (Fig. 2). Thus, it has been intensely debated whether the increase in social media use during the past decade has a causal role in the decline of adolescent mental health[40]. Indeed, rapid changes to the environment experienced before and during adolescence might be a fruitful area to explore when examining current mental health trends[41].

Although there are many environmental changes that could be relevant, a substantial body of research has emerged to investigate the potential link between social media use and declines in adolescent mental health[42,43] using various research approaches, including cross-sectional studies[44], longitudinal observational data analyses[45-47] and experimental studies[48,49]. However, the scientific results have been mixed and inconclusive (for reviews, see refs. 43,50–53), which has made it difficult to establish evidence-based recommendations, regulations and interventions aimed at ensuring that social media use is not harmful to adolescents[54-57].

Many researchers attribute the mixed results to insufficient study specificity. For instance, the relationship between social media use and mental health varies notably across individuals[45,58] and developmental time windows[59]. Yet studies often examine adolescents without differentiating them based on age or developmental stage[60], which prevents systematic accounts of individual and subgroup differences. Additionally, most studies only rely on self-reported measures of time spent on social media[61,62], and overlook more nuanced aspects of social media use such as the nature of the activities[63] and the content or features that users engage with[52]. These factors need to be considered to unpack any broader relationships[35,64-66]. Furthermore, the measurement of mental health often conflates positive and negative mental health outcomes as well as various mental health conditions, which could all be differentially related to social media use[52,67].

This research space presents substantial complexity[68]. There is an ever-increasing range of potential combinations of social media predictors, well-being and mental health outcomes and participant groups of varying backgrounds and demographics that can become the target of scientific investigation. However, the pressure to deliver policy and public-facing recommendations and interventions leaves little time to investigate comprehensively each of these combinations. Researchers need to be able to pinpoint quickly the research programmes with the maximum potential to create translational and real-world impact for adolescent mental health.

In this Review, we aim to delineate potential avenues for future research that could lead to concrete interventions to improve adolescent mental health by considering mechanisms at the nexus between pre-existing processes known to increase adolescent mental health vulnerability and digital affordances introduced by social media. First, we describe the affordance approach to understanding the effects of social media. We then draw upon research on adolescent development, mental health and social media to describe behavioural, cognitive and neurobiological mechanisms by which social media use might amplify changes during adolescent development to increase mental health vulnerability during this period of life. The specific mechanisms within each category were chosen because they have a strong evidence base showing that they undergo substantive changes during adolescent development, are implicated in mental health risk and can be modulated by social media affordances. Although the ways in which social media can also improve mental health resilience are not the focus of our Review and therefore are not reviewed fully here, they are briefly discussed in relation to each mechanism. Finally, we discuss future research focused on how to systematically test the intersection between social media and adolescent mental health.

Social media affordances

To study the impact of social media on adolescent mental health, its diverse design elements and highly individualized uses must be conceptualized. Initial research predominantly related access to or time spent on social media to mental health outcomes[46,69,70]. However, social media is not similar to a toxin or nutrient for which each exposure dose has a defined link to a health-related outcome (dose–response relationship)[56]. Social media is a diverse environment that cannot be summarized by the amount of time one spends interacting with it[71,72], and individual experiences are highly varied[45].

Previous psychological reviews often focused on social media 'features'[73] and 'affordances'[74] interchangeably. However, these terms have distinct definitions in communication science and information systems research. Social media features are components of the technology intentionally designed to enable users to perform specific actions, such as liking, reposting or uploading a story[75,76]. By contrast, affordances describe the perceptions of action possibilities users have
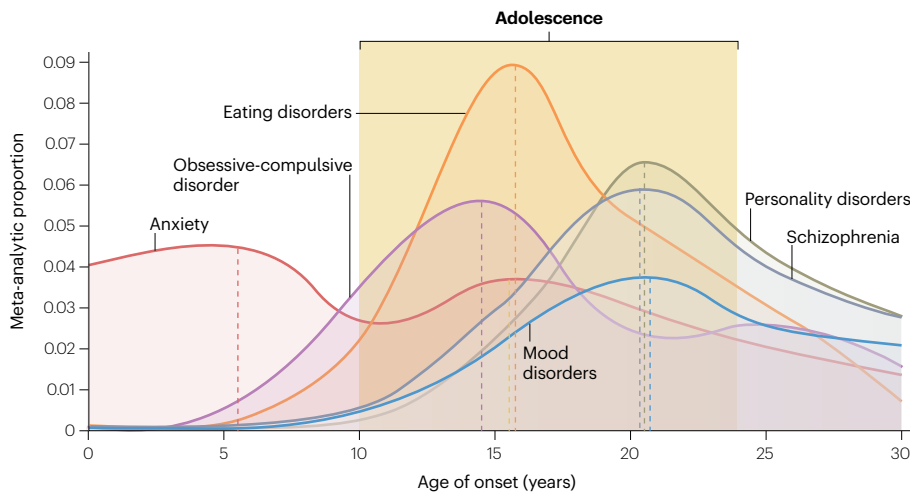
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Fig. 1 | **Age of onset for different mental disorders.** Meta-analytic proportion of age of onset of anxiety (red), obsessive-compulsive disorder (purple), eating disorders (orange), personality disorders (green), schizophrenia (grey) and mood disorders (blue). The peak age of onset (dotted lines) is 5.5 and 15.5 years for anxiety, 14.5 years for obsessive-compulsive disorder, 15.5 years for eating disorders and 20.5 years for personality disorders, schizophrenia and mood disorders. Adapted from ref. 258, CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

when engaging with social media and its features, such as anonymity (the difficulty with which social media users can identify the source of a message) and quantifiability (how countable information is).

The term 'affordance' came from ecological psychology and visuo-motor research, and was described as mainly determined by human perception[77]. 'Affordance' was later adopted for design and human–computer interaction contexts to refer to the action possibilities that are suggested to the user by the technology design[78]. Communication research synthesizes both views. Affordances are now typically under-stood as the perceived — and therefore flexible — action possibilities of digital environments, which are jointly shaped by the technology's features and users' idiosyncratic perceptions of those features[79].

Latent action possibilities can vary across different users, uses and technologies[79]. For example, 'stories' are a feature of Instagram designed to share content between users. Stories can also be described in terms of affordances when users perceive them as a way to determine how long their content remains available on the platform (persis-tence) or who can see that content (visibility)[80–84]. Low persistence (also termed ephemerality) and comparatively low visibility can be achieved through a technology feature (Instagram stories), but are not an outcome of technology use itself; they are instead perceived action possibilities that can vary across different technologies, users and designs[79].

The affordances approach is particularly valuable for theorizing at a level above individual social media apps or specific features, which makes this approach more resilient to technological changes or shifts in platform popularity[79,85]. However, the affordances approach can also be related back to specific types of social media by assessing the extent to which certain affordances are 'built into' a particular platform through feature design[35]. Furthermore, because affordances depend on individuals' perceptions and actions, they are more aligned than features with a neurocognitive and behavioural perspective to social media use. Affordances, similar to neurocognitive and behavioural research, emphasize the role of the user (how the technology is per-ceived, interpreted and used) rather than technology design per se. In this sense, the affordances approach is essential to overcome techno-logical determinism of mental health outcomes, which overly empha-sizes the role of technology as the driver of outcomes but overlooks the agency and impact of the people in question[86]. This flexibility and

alignment with psychological theory has contributed to the increasing popularity of the affordance approach[35,73,74,85,87] and previous reviews have explored relevant social media affordances in the context of interpersonal communication among adults and adolescents[35,88,89], adolescent body image concerns[73] and work contexts[33]. Here, we focus on the affordances of social media that are relevant for adolescent development and its intersection with mental health (Table 1).

Behavioural mechanisms

Adolescents often use social media differently to adults, engaging with different platforms and features and, potentially, perceiving or mak-ing use of affordances in distinctive ways[35]. These usage differences might interact with developmental characteristics and changes to amplify mental health vulnerability (Fig. 3). We examine two behav-ioural mechanisms that might govern the impact of social media use on mental health: risky posting behaviours and self-presentation.

Risky posting behaviour

Sensation-seeking peaks in adolescence and self-regulation abilities are still not fully developed in this period of life[90]. Thus, adolescents often engage in more risky behaviours than other age groups[91]. Adolescents are more likely to take risks in situations involving peers[92,93], perhaps because they are motivated to avoid social exclusion[94,95]. Whether ado-lescent risk-taking behaviour is inherently adaptive or maladaptive is debated. Although some risk-taking behaviours can be adaptive and part of typical development, others can increase mental health vulner-ability. For example, data from a prospective UK panel study of more than 5,500 young people showed that engaging in more risky behav-iours (including social and health risks) at age 16 years increases the odds of a range of adverse outcomes at age 18 years, such as depression, anxiety and substance abuse[96].

Social media can increase adolescents' engagement in risky behav-iours both in non-mediated and mediated environments (environments in which the behaviour is executed in or through a technology, such as a mobile phone and social media). First, affordances such as quantifi-ability in conjunction with visibility and association (the degree with which links between people, between people and content or between a presenter and their audience can be articulated) can promote more risky behaviours in non-mediated environments and in-person social
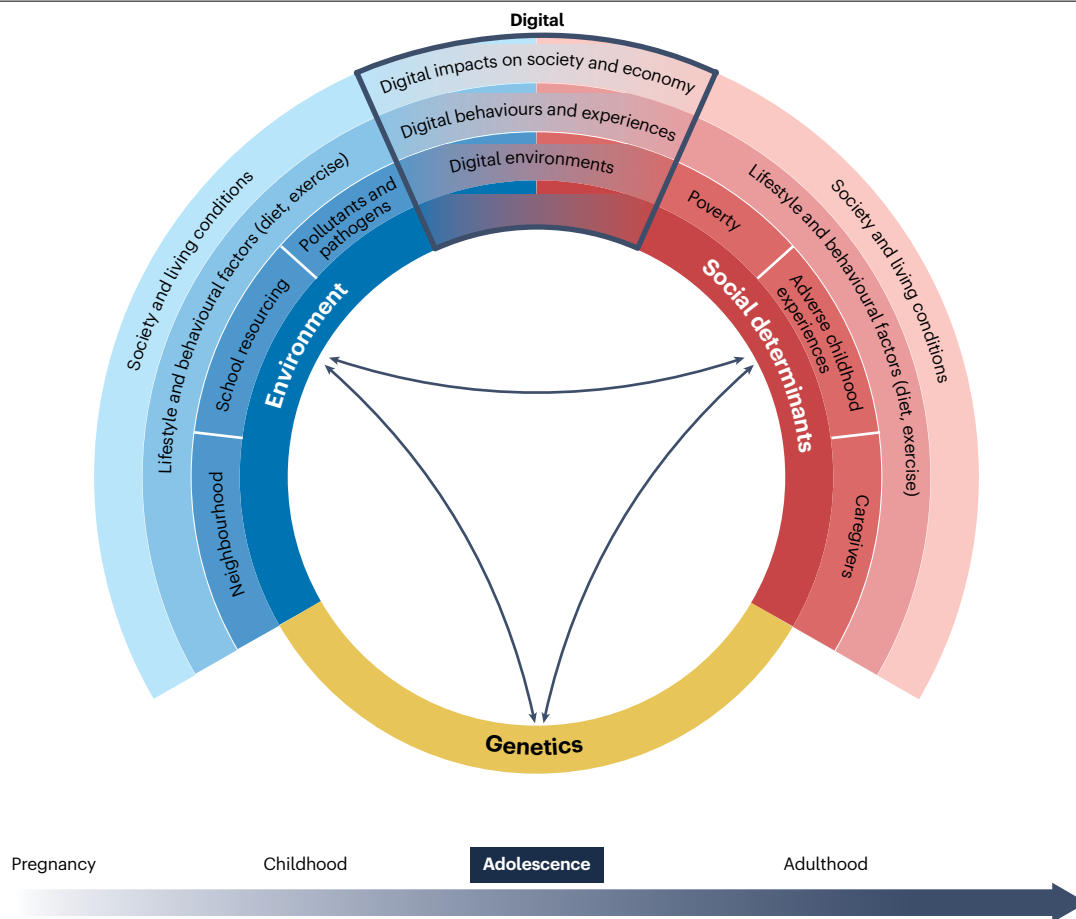
Fig. 2 | Factors contributing to adolescent mental health vulnerability. During adolescence, the interaction between genetic programming (yellow), social determinants (red) and environmental factors (blue), as well as the developmental changes discussed in this Review, increases the risk for onset of mental health conditions. Digital environments, mediated behaviours and experiences, and the impact that this technology has on society and economy more generally, are one aspect of the complex forces that might lead to the declines in adolescent mental health observed in the last decade. Adapted from ref. 259, Springer Nature Limited.

interactions. For example, posts from university students containing references to alcohol gain more likes than posts not referencing alcohol and liking such posts predicts an individual's subsequent drinking habits[97]. Users expecting likes from their audience are incentivized to engage in riskier posting behaviour (such as more frequent or more extreme posts containing references to alcohol). The relationship between risky online behaviour and offline behaviour is supported by meta-analyses that found a positive correlation between adolescents' social media use and their engagement in behaviours that might expose them to harm or risk of injury (for example, substance use or risky sexual behaviours)[98]. Further, affordances such as persistence and visibility can mean that risky behaviours in mediated and non-mediated environments remain public for long periods of time, potentially influencing how an adolescent is perceived by peers over the longer term[39,99].

Adolescence can also be a time of more risky social media use. For most forms of semi-public and public social media use, users typically do not know who exactly will be able to see their posts. Thus, adolescents need to self-present to an 'imagined audience'[100] and avoid posting the wrong kind of content as the boundaries between different social spheres collapse (context collapse[101]). However, young people

can underestimate the risks of disclosing revealing information in a social media environment[102]. Affordances such as visibility, replicability (social media posts remain in the system and can be screenshotted and shared even if they are later deleted[39]), association and persistence could heighten the risk of experiencing cyberbullying, victimization and online harassment[103]. For example, adolescents can forward privately received sexual images to larger friendship groups, increasing the risk of online harassment over the subject of the sexual images[104]. Further, low bandwidth (a relative lack of socio-emotional cues) and high anonymity have the potential to disinhibit interactions between users and make behaviours and reactions more extreme[105,106]. For example, anonymity was associated with more trolling behaviours during an online group discussion in an experiment with 242 undergraduate students[107].

Thus, social media might drive more risky behaviours in both mediated and non-mediated contexts, increasing mental health vulnerability. However, the evidence is still not clear cut and often discounts adolescent agency and understanding. For example, mixed-methods research has shown that young people often understand the risks of posting private or sexual content and use social media apps that ensure

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Table 1 | Affordances of social media that are relevant to the relationship between adolescent development and mental health

Affordance	Description	Example of affordance	Example associated mechanism	Example relationship with mental health	Refs.
Anonymity	The difficulty with which other social media agents (users, institutions or companies) can identify the source or sender of a message	Anonymity can easily be achieved in social media through fake accounts or using platforms that do not require sharing of identity	Behaviour: risky posting behaviour	High anonymity can disinhibit interactions and make behaviours or reactions more extreme	79,243
Association	The degree with which links between people, between people and content or between a presenter and their audience can be articulated	Friends lists facilitate the association between people. Comments or reposts facilitate the association between a person and content or ideas	Cognitive: social comparison	The ability to understand who is associated with whom can make it easier to judge social status or friendship ties, boosting comparison with others	84
Availability	How easily a user can reach and access the technology as well as how easily the user can be reached through the technology (also termed permanence or perpetual contact)	Mobile use of social media enables high availability	Neurobiological: reward and stress	Heightened availability of peers via mobile media can support increased checking behaviours, which might have long-term consequences for reward processing	244,245
Bandwidth	The breadth of socio-emotional cues that messages transmit; partially determined by the modality of channels (such as video chat or email), but also by users' adaption to channel limitations (for example, different language use, timing or interpunctuation), which can all influence a sense of social presence	Few social cues makes it difficult to judge what people think of a behaviour or posts on social media	Behaviour: risky posting behaviour	Low bandwidth can potentially disinhibit interactions and make behaviours or reactions more extreme	81,246,247
Editability	The degree to which messages can be carefully crafted, refined and edited; also called rehearsability, which emphasizes the ability to not only edit but also consider material before posting	Posts can be drafted and re-drafted many times before sharing on social media	Behaviour: self-presentation and identity	The editability of profiles enables users to curate and present their online identity, potentially facilitating identity development	35,84,248
Persistence	The degree to which messages remain accessible to receivers in the same form as originally crafted and displayed by the sender	Auto-deletion features enable ephemeral messages with low persistence	Behaviour: self-presentation and identity	The persistence of social media posts (for example, after screenshotting) could limit adolescents' ability to freely explore their identity	79,80, 82,84
Personalization	The degree to which messages are tailored (by senders or by recommendation algorithms) to fit the identity, preferences or expectations of the receiver	TikTok algorithms enable users to consume content that is highly relevant to them	Cognitive: self-concept development	The personalization of content can change what young people see on social media feeds, influencing self-concept development	81,143, 249,250
Quantifiability	How countable information is, especially if it formally quantifies aspects of social life that were previously not as clearly labelled with quantitative values	Numbers of friends or followers, and social feedback and content popularity, which are quantified through the 'like' button or similar one-click reactions	Cognitive: social inclusion and exclusion	The quantifiability of social feedback could make it easier to feel excluded or unpopular (for example, when not receiving likes)	35,152,194, 251–253
Replicability	The ease with which messages can be duplicated and shared with others, via the same or other digital channels	Features that enable forwarding content across platforms; if this is not built into the system, users might find other means (for example, through screenshots)	Behaviour: risky posting behaviour	Replicability can amplify the risk of activities such as sexting	254
Synchronicity	The degree to which an interaction is perceived as happening simultaneously, in real time	Feed posts are classically more strongly associated with asynchronous communication, and instant messengers with synchronous communication	Cognitive: social feedback	Asynchronicity of communication makes it more likely that adolescents have time to ruminate about potential social feedback, especially when presumed negative	35,81,255

Table 1 (continued) | Affordances of social media that are relevant to the relationship between adolescent development and mental health

Affordance	Description	Example of affordance	Example associated mechanism	Example relationship with mental health	Refs.
Variability of social rewards	The degree to which social interaction and feedback occur on variable time schedules	The time lag between sending a message or posting and the responses and reactions to these actions is unknown	Neurobiological: reward	Quantified social feedback from peers can support increased checking behaviours, which might have long-term consequences on reward processing	160,217,256
Verifiability	How easily a message's truthfulness can be cross-examined and authenticated by others	Verifiability is implicated in inauthentic self-presentations (such as using visual filters), scams (such as catfishing) and other forms of deception (such as misinformation or fake news)	Cognitive: social comparison	If the verifiability of individuals or their posts is low, it is difficult to gauge the authenticity of their self-presentations that form the basis for social comparisons	33,143,249, 250,252,257
Visibility	The relative ease with which messages can be located and seen by others; sometimes also termed publicness (or scalability if approached from the sender's perspective)	Visibility enables users to choose the size and nature of their audiences and influences whether information is considered private, semi-public or public	Cognitive: self-presentation and identity	Profile visibility enables users to curate and try out different private and public online identities, potentially facilitating identity development	83,84,255

that posts are deleted and inaccessible after short periods of time to counteract them[39] (even though posts can still be captured in the meantime). Future work will therefore need to investigate how adolescents understand and balance such risks and how such processes relate to social media's impact on mental health.

Self-presentation and identity

The adolescent period is characterized by an abundance of self-presentation activities on social media[74], where the drive to present oneself becomes a fundamental motivation for engagement[108]. These activities include disclosing, concealing and modifying one's true self, and might involve deception, to convey a desired impression to an audience[109]. Compared with adults, adolescents more frequently take part in self-presentation[102], which can encompass both realistic and idealized portrayals of themselves[110]. In adults, authentic self-presentation has been associated with increased well-being, and inauthentic presentation (such as when a person describes themselves in ways not aligned with their true self) has been associated with decreased well-being[111–113].

Several social media affordances shape the self-presentation behaviours of adolescents. For example, the editability of social media profiles enables users to curate their online identity[84,114]. Editability is further enhanced by highly visible (public) self-presentations. Additionally, the constant availability of social media platforms enables adolescents to access and engage with their profiles at any time, and provides them with rapid quantitative feedback about their popularity among peers[89,115]. People receive more direct and public feedback on their self-presentation on social media than in other types of environment[116,117]. The affordances associated with self-presentation can have a particular impact during adolescence, a period characterized by identity development and exploration.

Social media environments might provide more opportunities than offline environments for shaping one's identity. Indeed, public self-presentation has been found to invoke more prominent identity shifts (substantial changes in identity) compared with private self-presentation[118,119]. Concerns have been raised that higher Internet use

is associated with decreased self-concept clarity. Only one study of 101 adolescents as well as adults reviewed in a 2021 meta-analysis[120] showed that the intensity of Facebook use (measured by the Facebook Intensity Scale) predicted a longitudinal decline in self-concept clarity 3 months later, but the converse was not the case and changes in self-concept clarity did not predict Facebook use[121]. This result is still not enough to show a causal relationship[121]. Further, the affordances of persistence and replicability could also curtail adolescents' ability to explore their identity freely[122].

By contrast, qualitative research has highlighted that social media enables adolescents to broaden their horizons, explore their identity and identify and reaffirm their values[123]. Social media can help self-presentation by enabling adolescents to elaborate on various aspects of their identity, such as ethnicity and race[124] or sexuality[125]. Social media affordances such as editability and visibility can also facilitate this process. Adolescents can modify and curate self-presentations online, try out new identities or express previously undisclosed aspects of their identity[126,127]. They can leverage social media affordances to present different facets of themselves to various social groups by using different profiles, platforms and self-censorship and curation of posts[128,129]. Presenting and exploring different aspects of one's identity can have mental health implications for minority teens. Emerging research shows a positive correlation between well-being and problematic Internet use in transgender, non-binary and gender-diverse adolescents (age 13–18 years), and positive sentiment has been associated with online identity disclosures in transgender individuals with supportive networks (both adolescent and adult)[130,131].

Cognitive mechanisms

Adolescents and adults might experience different socio-cognitive impacts from the same social media activity. In this section, we review four cognitive mechanisms via which social media and its affordances might influence the link between adolescent development and mental health vulnerabilities (Fig. 3). These mechanisms (self-concept development, social comparison, social feedback and exclusion) roughly

align with a previous review that examined self-esteem and social media use[115].

Self-concept development

Self-concept refers to a person's beliefs and evaluations about their own qualities and traits[132], which first develops and becomes more complex throughout childhood and then accelerates its development during adolescence[133–135]. Self-concept is shaped by socio-emotional processes such as self-appraisal and social feedback[134]. A negative and unstable self-concept has been associated with negative mental health outcomes[136,137].

Perspective-taking abilities also develop during adolescence[133,138,139], as does the processing of self-relevant stimuli (measured by self-referential memory tasks, which assess memory for self-referential trait adjectives[140,141]). During adolescence, direct self-evaluations and reflected self-evaluations (how someone thinks others evaluate them) become more similar. Further, self-evaluations have a distinct positive bias during childhood, but this positivity bias decreases in adolescence as evaluations of the self are integrated with judgements of other people's perspectives[142]. Indeed, negative self-evaluations peak in late adolescence (around age 19 years)[140].

The impact of social media on the development of self-concept could be heightened during adolescence because of affordances such as personalization of content[143] (the degree to which content can be tailored to fit THE identity, preferences or expectations of the receiver), which adapts the information young people are exposed to. Other affordances with similar impacts are quantifiability, availability (the accessibility of the technology as well as the user's accessibility through the technology) and public visibility of interactions[89], which render the evaluations of others more prominent and omnipresent. The prominence of social evaluation can pose long-term risks to mental health under certain conditions and for some users[144,145]. For example, receiving negative evaluations from others or being exposed to cyberbullying behaviours[146,147] can, potentially, have heightened impact at times of self-concept development.

A pioneering cross-sectional study of 150 adolescents showed that direct self-evaluations are more similar to reflected self-evaluations, and self-evaluations are more negative, in adolescents aged 11–21 years who estimate spending more time on social media[148]. Further, longitudinal data have shown bidirectional negative links between social media use and satisfaction with domains of the self (such as satisfaction with family, friends or schoolwork)[47].

Although large-scale evidence is still unavailable, these findings raise the interesting prospect that social media might have a negative influence on perspective-taking and self-concept. There is less evidence for the potential positive influence of social media on these aspects of adolescent development, demonstrating an important research gap. Some researchers hypothesize that social media enables self-concept unification because it provides ample opportunity to find validation[89]. Research has also discussed how algorithmic curation of personalized social media feeds (for example, TikTok algorithms tailoring videos viewed to the user's interests) enables users to reflect on their self-concept by being exposed to others' experiences and perspectives[143], an area where future research can provide important insights.
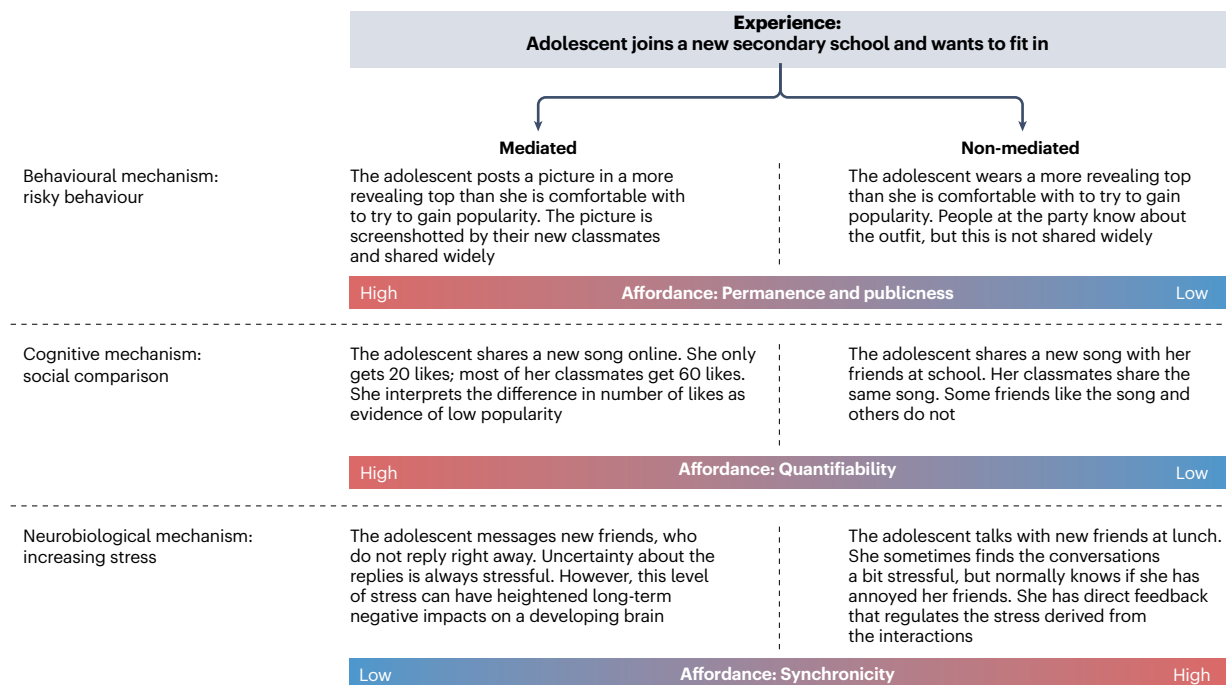

Fig. 3 | Examples of social media affordances in adolescence. Social media affordances can amplify the impact that common adolescent developmental mechanisms (behavioural, cognitive and neurobiological) have on mental health. At the behavioural level (top), affordances such as permanence and publicness lead to an increased impact of risk-taking behaviour on mental health compared with similar behaviours in non-mediated environments. At the cognitive level (middle), high quantifiability influences the effects of social comparison. At the neurobiological level (bottom), low synchronicity can amplify the effects of stress on the developing brain.

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Social comparison

Social comparison (thinking about information about other people in relation to the self[149]) also influences self-concept development and becomes particularly important during adolescence[133,150]. There are a range of social media affordances that can amplify the impact of social comparison on mental health. For example, quantifiability enables like or follower counts to be easily compared with others as a sign of status, which facilitates social ranking[151–154]. Studies of older adolescents and adults aged, on average, 20 years have also found that the number of likes or reactions received predict, in part, how successful users judge their self-presentation posts on Facebook[155]. Furthermore, personalization enables the content that users see on social media to be curated so as to be highly relevant and interesting for them, which should intensify comparisons. For example, an adolescent interested in sports and fitness content will receive personalized recommendations fitting those interests, which should increase the likelihood of comparisons with people portrayed in this content. In turn, the affordance of association can help adolescents surround themselves with similar peers and public personae online, enhancing social comparison effects[63,156]. Being able to edit posts (via the affordance of editability) has been argued to contribute to the positivity bias on social media: what is portrayed online is often more positive than the offline experience. Thus, upward comparisons are more likely to happen in online spaces than downward or lateral comparisons[157]. Lastly, the verifiability of others' idealized self-presentations is often low, meaning that users have insufficient cues to gauge their authenticity[158].

Engaging in comparisons on social media has been associated with depression in correlational studies[159]. Furthermore, qualitative research has shown that not receiving as many positive evaluations as expected (or if positive evaluations are not provided quickly enough) increases negative emotions in children and adolescents aged between age 9 and 19 years[39]. This result aligns with a reinforcement learning modelling study of Instagram data, which found that the likes a user receives on their own posts become less valuable and less predictive of future posting behaviour if others in their network receive more likes on their posts[160]. Although this study did not measure mood or mental health, it shows that the value of the likes are not static but inherently social; their impact depends on how many are typically received by other people in the same network.

Among the different types of social comparison that adolescents engage in (comparing one's achievements, social status or lifestyle), the most substantial concerns have been raised about body-related comparisons. One review suggested that social media affordances create a 'perfect storm' for body image concerns that can contribute to both socio-emotional and eating disorders[73]. Social media affordances might increase young people's focus on other people's appearances as well as on their own appearance by showing idealized, highly edited images, providing quantified feedback and making the ability to associate and compare oneself with peers constantly available[161,162]. The latter puts adolescents who are less popular or receive less social support at particular risk of low self-image and social distress[35].

Affordances enable more prominent and explicit social comparisons in social media environments relative to offline environments[158,159,163–165]. However, this association could have a positive impact on mental health[164,166]. Initial evidence suggests beneficial outcomes of upward comparisons on social media, which can motivate behaviour change and yield positive downstream effects on mental health[164,166]. Positive motivational effects (inspiration) have been observed among young adults for topics such as travelling and exploring nature, as well as fitness and other health behaviours, which can all improve mental health[167]. Importantly, inspiration experiences are not a niche phenomenon on social media: an experience sampling study of 353 Dutch adolescents (mean age 13–15 years) found that participants reported some level of social media-induced inspiration in 33% of the times they were asked to report on this over the course of 3 weeks[168]. Several experimental and longitudinal studies show that inspiration is linked to upward comparison on social media[157,164,166]. However, the positive, motivating side of social comparison on social media has only been examined in a few studies and requires additional investigation.

Social feedback

Adolescence is also a period of social reorientation, when peers tend to become more important than family[169], peer acceptance becomes increasingly relevant[170–172] and young people spend increasing amounts of time with peers[173]. In parallel, there is a heightened sensitivity to negative socio-emotional or self-referential cues[140,174], higher expectation of being rejected by others[175] and internalization of such rejection[142,176] compared with other phases in life development. A meta-analysis of both adolescents and adults found that oversensitivity to social rejection is moderately associated with both depression and anxiety[177].

Social media affordances might amplify the potential impact of social feedback on mental health. Wanting to be accepted by peers and increased susceptibility to social rewards could be a motivator for using social media in the first place[178]. Indeed, receiving likes as social reward activated areas of the brain (such as the nucleus accumbens) that are also activated by monetary reward[179]. Quantifiability amplifies peer acceptance and rejection (via like counts), and social rejection has been linked to adverse mental health outcomes[170,180–182]. Social media can also increase feelings of being evaluated, the risk of social rejection and rumination about potential rejection due to affordances such as quantifiability, synchronicity (the degree to which an interaction happens in real time) and variability of social rewards (the degree to which social interaction and feedback occur on variable time schedules). For example, one study of undergraduate students found that active communication such as messaging was associated with feeling better after Facebook use; however, this was not the case if the communication led to negative feelings such as rumination (for example, after no responses to the messages)[183].

In a study assessing threatened social evaluation online[184], participants were asked to record a statement about themselves and were told their statements would be rated by others. To increase the authenticity of the threat, participants were asked to rate other people's recordings. Threatened social evaluation online in this study decreased mood, most prominently in people with high sensitivity to social rejection. Adolescents who are more sensitive to social rejection report more severe depressive symptoms and maladaptive ruminative brooding in both mediated and non-mediated social environments, and this association is most prominent in early adolescence[185]. Not receiving as much online social approval as peers led to more severe depressive symptoms in a study of American ninth-grade adolescents (between age 14 and 15 years), especially those who were already experiencing peer victimization[153]. Furthermore, individuals with lower self-esteem post more negative and less positive content than individuals with higher self-esteem. Posted negative content receives less social reward and recognition from others than positive content, possibly creating a vicious cycle[186]. Negative experiences pertaining to social exclusion and status are also risk factors for socio-emotional disorders[180].

The impact of social media experiences on self-esteem can be very heterogeneous, varying substantially across individuals. As a benefit, positive social feedback obtained via social media can increase users' self-esteem[115], an association also found among adolescents[187]. For instance, receiving likes on one's profile or posted photographs can bolster self-esteem in the short term[144,188]. A study linking behavioural data and self-reports from Facebook users found that receiving quick responses on public posts increased a sense of social support and decreased loneliness[189]. Furthermore, a review of reviews consistently documented that users who report more social media use also perceive themselves to have more social resources and support online[52], although this association has mostly been studied among young adults using social network sites such as Facebook. Whether such social feedback benefits extend to adolescents' use of platforms centred on content consumption (such as TikTok or Instagram) is an open question.

Social inclusion and exclusion
Adolescents are more sensitive to the negative emotional impacts of being excluded than are adults[170,190]. It has been proposed that, as the importance of social affiliation increases during this period of life[134,191,192], adolescents are more sensitive to a range of social stimuli, regardless of valence[193]. These include social feedback (such as compliments or likes)[95,194], negative socio-emotional cues (such as negative facial expressions or social exclusion)[174] and social rejection[172,185]. By contrast, social inclusion (via friendships in adolescence) is protective against emotional disorders[195] and more social support is related to higher adolescent well-being[196].

Experiencing ostracism and exclusion online decreases self-esteem and positive emotion[197]. This association has been found in vignette experiments where participants received no, only a few or a lot of likes[198], or experiments that used mock-ups of social media sites where others received more likes than participants[153]. Being ostracized (not receiving attention or feedback) or rejected through social media features (receiving dislikes and no likes) is also associated with a reduced sense of belonging, meaningfulness, self-esteem and control[199]. Similar results were found when ostracism was experienced over messaging apps, such as not receiving a reply via WhatsApp[200].

Evidence on whether social media also enables adolescents to experience positive social inclusion is mostly indirect and mixed. Some longitudinal surveys have found that prosocial feedback received on social media during major life events (such as university admissions) helps to buffer against stress[201]. Adult participants of a longitudinal study reported that social media offered more informational support than offline contexts, but offline contexts more often offered emotional or instrumental support[202]. Higher social network site use is, on average, associated with a perception of having more social resources and support in adults (for an overview of meta-analyses, see ref. 52). However, most of these studies have not investigated social support among adolescents, and it is unclear whether early findings (for example, on Facebook or Twitter) generalize to a social media landscape more strongly characterized by content consumption than social interaction (such as Instagram or TikTok).

Still, a review of social media use and offline interpersonal outcomes among adolescents documents both positive (sense of belonging and social capital) and negative (alienation from peers and perceived isolation) correlates[203]. Experience sampling research on emotional support among young adults has further shown that online social support is received and perceived as effective, and its perceived effectiveness is similar to in-person social support[204]. Social media use also has complex associations with friendship closeness among adolescents. For example, one experience sampling study found that greater use of WhatsApp or Instagram is associated with higher friendship closeness among adolescents; however, within-person examinations over time showed small negative associations[205].

Neurobiological mechanisms
The long-term impact of environmental changes such as social media use on mental health might be amplified because adolescence is a period of considerable neurobiological development[95] (Fig. 3). During adolescence, overall cortical grey matter declines and white matter increases[206,207]. Development is particularly protracted in brain regions associated with social cognition and executive functions such as planning, decision-making and inhibiting prepotent responses. The changes in grey and white matter are thought to reflect axonal growth, myelination and synaptic reorganization, which are mechanisms of neuroplasticity influenced by the environment[208]. For example, research in rodents has demonstrated that adolescence is a sensitive period for social input, and that social isolation in adolescence has unique and more deleterious consequences for neural, behavioural and mental health development than social isolation before puberty or in adulthood[206,209]. There is evidence that brain regions involved in motivation and reward show greater activation to rewarding and motivational stimuli (such as appetitive stimuli and the presence of peers) in early and/or mid adolescence compared with other age groups[210–214].

Little is known about the potential links between social media and neurodevelopment due to the paucity of research investigating these associations. Furthermore, causal chains (for example, social media increasing stress, which in turn influences the brain) have not yet been accurately delineated. However, it would be amiss not to recognize that brain development during adolescence forms part of the biological basis of mental health vulnerability and should therefore be considered. Indeed, the brain is proposed to be particularly plastic in adolescence and susceptible to environmental stimuli, both positive and negative[208]. Thus, even if adults and adolescents experienced the same affective consequences from social media use (such as increases in peer comparison or stress), these consequences might have a greater impact in adolescence.

A cross-sectional study (with some longitudinal elements) suggested that habitual checking of social media (for example, checking for rewards such as likes) might exacerbate reward sensitivity processes, leading to long-term hypersensitization of the reward system[215]. Specifically, frequently checking social media was associated with reduced activation in brain regions such as the dorsolateral prefrontal cortex and the amygdala in response to anticipated social feedback in young people. Brain activation during the same social feedback task was measured over subsequent years. Upon follow-up, anticipating feedback was associated with increased activation of the same brain regions among the individuals who checked social media frequently initially[215]. Although longitudinal brain imaging measurements enabled trajectories of brain development to be specified, the measures of social media use were only acquired once in the first wave of data collection. The study therefore cannot account for confounds such as personality traits, which might influence both social media checking behaviours and brain development. Other studies of digital screen use and brain development have found no impact on adolescent functional brain organization[216].

Brain development and heightened neuroplasticity[208] render adolescence a particularly sensitive period with potentially long-term

Box 1

Digital stress

Digital stress is not a unified construct. Thematic content analyses have categorized digital stress into type I stressors (for example, mean attacks, cyberbullying or shaming) and type II stressors (for example, interpersonal stress due to pressure to stay available)[260]. Other reviews have noted its complexity, and categorized digital stress into availability stress (stress that results from having to be constantly available), approval anxiety (anxiety regarding others' reaction to their own profile, posts or activities online), fear of missing out (stress about being absent from or not experiencing others' rewarding experiences) and communication overload (stress due to the scale, intensity and frequency of online communication)[261].

Digital stress has been systematically linked to negative mental health outcomes. Higher digital stress was longitudinally associated with higher depressive symptoms in a questionnaire study[262]. Higher social media stress was also longitudinally related to poorer sleep outcomes in girls (but not boys)[263]. Studies and reviews have linked cyberbullying victimization (a highly stressful experience) to decreased mental health outcomes such as depression, and psychosocial outcomes such as self-esteem[103,146,147,264,265]. A systematic review of both adolescents and adults found a medium association (r=0.26–0.34) between different components of digital stress and psychological distress outcomes such as anxiety, depression or loneliness, which was not moderated by age or sex (except for connection overload)[266]. However, the causal structure giving rise to such results is still far from clear. For example, surveys have linked higher stress levels to more problematic social media use and fear of missing out[267,268].

Thus, the impact of digital stress on mental health is probably complex and influenced by the type of digital stressor and various affordances. For example, visibility and availability increase fear of negative public evaluation[269] and high availability and a social norm of responding quickly to messages drive constant monitoring in adolescents due to a persistent fear of upsetting friends[270].

A range of relevant evidence from qualitative and quantitative studies documents that adolescents often ruminate about online interactions and messages. For example, online salience (constantly thinking about communication, content or events happening online) was positively associated with stress on both between-person and within-person levels in a cross-sectional quota sample of adults and three diary studies of young adults[271,272]. Online salience has also been associated with lower well-being in a pre-registered study of momentary self-reports from young adults with logged online behaviours. However, this study also noted that positive thoughts were related to higher well-being[273]. Furthermore, although some studies found no associations between the amount of communication and digital stress[272], a cross-sectional study found that younger users' (age 14–34 years and 35–49 years) perception of social pressure to be constantly available was related to communication load (measured by questions about the amount of use, as well as the urge to check email and social media) and Internet multitasking, whereas this was not the case for older users aged 50–85 years[274]. By contrast, communication load and perceived stress were associated only among older users.

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impacts into adulthood. It is possible that social media affordances that underpin increased checking and reward-seeking behaviours (such as quantifiability, variability of social rewards and permanent availability of peers) might have long-term consequences on reward processing when experienced during adolescence. However, this suggestion is still speculative and not backed up by evidence[217].

Stress is another example of the potential amplifying effect of social media on adolescent mental health vulnerability due to neural development. Adolescents show higher stress reactivity because of maturational changes to, and increased reactivity in, the hypothalamic–pituitary–adrenal axis[218,219]. Compared with children and adults, adolescents experience an increase in self-consciousness and associated emotional states such as self-reported embarrassment and related physiological measures of arousal (such as skin conductance), and heightened neural response patterns compared with adults, when being evaluated or observed by peers[220]. Similarly, adolescents (age 13–17 years) show higher stress responses (higher levels of cortisol or blood pressure) compared with children (age 7–12 years) when they perform in front of others or experience social rejection[221].

Such changes in adolescence might confer heightened risk for the onset of mental health conditions, especially socio-emotional disorders[6]. Both adolescent rodents and humans show prolonged hypothalamic–pituitary–adrenal activation after experiencing stress compared with conspecifics of different ages[218,219]. In animal models,

stress during adolescence has been shown to result in increased anxiety levels in adulthood[222] and alterations in emotional and cognitive development[223]. Furthermore, human studies have linked stress in adolescence to a higher risk of mental health disorder onset[218] and reviews of cross-species work have illustrated a range of brain changes due to adolescent stress[224,225].

There is still little conclusive neurobiological evidence about social media use and stress, and a lack of understanding about which affordances might be involved (although there has been a range of work studying digital stress; Box 1). Studies of changes in cortisol levels or hypothalamic–pituitary–adrenal functioning and their relation to social media use have been mixed and inconclusive[226,227]. These results could be due to the challenge of studying stress responses in adolescents, particularly as cortisol fluctuates across the day and one-point readings can be unreliable. However, the increased stress sensitivity during the adolescent developmental period might mean that social media use can have a long-term influence on mental health due to neurobiological mechanisms. These processes are therefore important to understand in future research.

Summary and future directions

To help to understand the potential role of social media in the decline of adolescent mental health over the past decade, researchers should study the mechanisms linking social media, adolescent development

and mental health. Specifically, social media environments might amplify the socio-cognitive processes that render adolescents more vulnerable to mental health conditions in the first place. We outline various mechanisms at three levels of adolescent development — behavioural, cognitive and neurobiological — that could be involved in the decline of adolescent mental health as a function of social media engagement. To do so, we delineate specific social media affordances, such as quantification of social feedback or anonymity, which can also have positive impacts on mental health.

Our Review sets out clear recommendations for future research on the intersection of social media and adolescent mental health. The foundation of this research lies in the existing literature investigating the underlying processes that heighten adolescents' risk of developing socio-emotional disorders. Zooming in on the potential mechanistic targets impacted by social media uses and affordances will produce specific research questions to facilitate controlled and systematic scientific inquiry relevant for intervention and translation. This approach encourages researchers to pinpoint the mechanisms and levels of explanation they want to include and will enable them to identify what factors to additionally consider, such as participants' age[60], the specific mental health outcomes being measured, the types of social media being examined and the populations under study[52,228]. Targeted and effective research should prioritize the most promising areas of study and acknowledge that all research approaches have inherent limitations[229]. Researchers must embrace methodological diversity, which in turn will facilitate triangulation. Surveys, experience sampling designs in conjunction with digital trace data, as well as experimental or neuroimaging paradigms and computational modelling (such as reinforcement learning) can all be used to address research questions comprehensively[230]. Employing such a multi-method approach enables the convergence of evidence and strengthens the reliability of findings[231].

Mental health and developmental research can also become more applicable to the study of social media by considering how studies might already be exploring features of the digital environment, such as its design features and perceived affordances. Many cognitive neuroscience studies that investigate social processes and mental health during adolescence necessarily design tasks that can be completed in controlled experimental or brain scanning environments. Consequently, they tend to focus on digitally mediated interactions. However, researchers conceptualize and generalize their results to face-to-face interactions. For example, it is common across the discipline to not explicitly describe the interactions under study as being about social processes in digital environments (such as studies that assess social feedback based on the number of 'thumbs up' or 'thumbs down' received in social media[232]). Considering whether cognitive neuroscience studies include key affordances of mediated (or non-mediated) environments, and discussing these in published papers, will make studies searchable within the field of social media research, enabling researchers to broaden the impact of their work and systematically specify generalizations to offline environments[233].

Box 2

Effects of mental health on social media use

Although a lot of scientific discussion has focused on the impact of social media use on mental health, cross-sectional studies cannot differentiate between whether social media use is influencing mental health or mental health is influencing social media use, or a third factor is influencing both[51]. It is likely that mental health status influences social media use creating reinforcing cycles of behaviour, something that has been considered in the communication sciences literature under the term 'transactional media effects'[58,236,237]. According to communication science models, media use and its consequences are components of reciprocal processes[275].

There are similar models in mental health research. For example, people's moods influence their judgements of events, which can lead to self-perpetuating cycles of negativity (or positivity); a mechanism called 'mood congruency'[276]. Behavioural studies have also shown that people experiencing poor mental health behave in ways that decrease their opportunity to experience environmental reward such as social activities, maintaining poor mental health[277,278]. Although for many people these behaviours are a form of coping (for example, by avoiding stressful circumstances), they often worsen symptoms of mental health conditions[279].

Some longitudinal studies found that a decrease in adolescent well-being predicted an increase in social media use 1 year later[47,59]. However, other studies have found no relationships between well-being and social media use over long-term or daily time windows[45,46].

One reason behind the heterogeneity of the results could be that how mental health impacts social media use is highly individual[45,280].

Knowledge on the impact of mental health on social media use is still in its infancy and studies struggle to reach coherent conclusions. However, findings from the mental health literature can be used to generate hypotheses about how aspects of mental health might impact social media use. For example, it has been repeatedly found that young people with anxiety or eating disorders engage in more social comparisons than individuals without these disorders[281,282], and adolescents with depression report more unfavourable social comparisons on social media than adolescents without depression[283]. Similar results have been found for social feedback seeking (for example, reassurance), including in social media environments[159]. Specifically, depressive symptoms were more associated with social comparison and feedback seeking, and these associations were stronger in women and in adolescents who were less popular. Individuals from the general population with lower self-esteem post more negative and less positive content than individuals with higher self-esteem, which in turn is associated with receiving less positive feedback from others[185]. There are therefore a wide range of possible ways in which diverse aspects of mental health might influence specific facets of how social media is used — and, in turn, how it ends up impacting the user.

Review article

To bridge the gap between knowledge about mediated and non-mediated social environments, it is essential to directly compare the two[233]. It is often assumed that negative experiences online have a detrimental impact on mental health. However, it remains unclear whether this mechanism is present in both mediated and non-mediated spaces or whether it is specific to the mediated context. For instance, our Review highlights that the quantification of social feedback through likes is an important affordance of social media[160]. Feedback on social media platforms might therefore elicit a greater sense of certainty because it is quantified compared with the more subjective and open-to-interpretation feedback received face to face[151]. Conducting experiments in which participants receive feedback that is more or less quantified and uncertain, specifically designed to compare mediated and non-mediated environments, would provide valuable insights. Such research efforts could also establish connections with computational neuroscience studies demonstrating that people tend to learn faster from stimuli that are less uncertain[234].

We have chosen not to make recommendations concerning interventions targeting social media use to improve adolescent mental health for several reasons. First, we did not fully consider the bidirectional interactions between environment and development[35,235], or the factors modulating adolescents' differential susceptibility to the effects of social media[45,58]. For example, mental health status also influences how social media is used[47,58,59,236,237] (Box 2). These bidirectional interactions could be addressed using network or complexity science approaches[238]. Second, we do not yet know how the potential mechanisms by which social media might increase mental health vulnerability compare in magnitude, importance, scale and ease and/or cost of intervention with other factors and mechanisms that are already well known to influence mental health, such as poverty or loneliness. Last, social media use will probably interact with these predictors in ways that have not been delineated and can also support mental health resilience (for example, through social support or online self-help programmes). These complexities should be considered in future research, which will need to pinpoint not just the existence of mechanisms but their relative importance, to identify policy and intervention priorities.

Our Review has used a broad definition of mental health. Focusing on specific diagnostic or transdiagnostic symptomatology might reveal different mechanisms of interest. Furthermore, our Review is limited to mechanisms related to behaviour and neurocognitive development, disregarding other levels of explanation (such as genetics and culture)[34], and also studying predominately Western-centric samples[239]. Mechanisms do not operate solely in linear pathways but exist within networks of interacting risk and resilience factors, characterized by non-linear and complex dynamics across diverse timescales[9]. Mechanisms and predisposing factors can interact and combine, amplifying mental health vulnerability. Mental health can be considered a dynamic system in which gradual changes to external conditions can have substantial downstream consequences due to system properties such as feedback loops[240–242]. These consequences are especially prominent in times of change and pre-existing vulnerability, such as adolescence[10].

Indeed, if social media is a contributing factor to the current decline in adolescent mental health, as is commonly assumed, then it is important to identify and investigate mechanisms that are specifically tailored to the adolescent age range and make the case for why they matter. Without a thorough examination of these mechanisms and policy analysis to indicate whether they should be a priority to address, there is insufficient evidence to support the hypothesis that social media is the primary — or even just an influential and important — driver of mental health declines. Researchers need to stop studying social media as monolithic and uniform, and instead study its features, affordances and outcomes by leveraging a range of methods including experiments, questionnaires, qualitative research and industry data. Ultimately, this comprehensive approach will enhance researchers' ability to address the potential challenges that the digital era poses on adolescent mental health.

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Review article

Author contributions

A.O. conceptualized the manuscript; A.O and A.M wrote the original draft; A.O., A.M., T.D. and S.-J.B. reviewed and edited the manuscript. All authors contributed substantially to discussion of the content, and reviewed and/or edited the manuscript before submission.

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The authors declare no competing interests.

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