The effect of pubertal status on self-regulation of behavior – a systematic review

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Abstract

Behavioral self-regulation (BSR) refers to a set of abilities such as cool and hot executive functions, that enable flexible, adaptive, and goal-directed regulation of behavior. During adolescence, BSR improves as individuals age and learn from their experiences. Crucially, BSR is also influenced by maturational changes related to pubertal development. However, the contribution of pubertal status to BSR development beyond age-related effects is unclear. Here, we performed a systematic review of the literature to investigate effects of pubertal status that can be separated from age effects. We identified 113 studies reporting results on the relationship between pubertal status and BSR measures, but most of them were not informative for our review question because they did not properly adjust for age effects, or manipulated pubertal data in ways that no longer reflected the participants' pubertal status. The 26 remaining eligible studies used a heterogeneous set of tasks and questionnaires to assess BSR-related capacities. More than a third of these studies found no pubertal effects, while the remainder reported a mix of positive and negative effects, with few clear patterns. Additionally, there were common methodological shortcomings in this literature that significantly limited the strength of the evidence. So, despite indirect evidence for pubertal effects on BSR, our review showed a lack of strong direct evidence for substantial effects. We conclude with a discussion of the implications of our findings for current theories of BSR development during adolescence, and present suggestions for dealing with the current methodological shortcomings in future studies.

Keywords: Adolescence, puberty, self-control, self-regulation, executive functions.

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Introduction

Adolescence is a time of change, a period of significant development that comes with new roles, rights, and responsibilities. These changes bring about modifications in behavior and cognition as adolescents explore their environment and learn to deal with myriad new challenges (Crone, 2009; Icenogle and Cauffman, 2021; Icenogle et al., 2019; Steinberg et al., 2017). Learning from life experiences as adolescents grow older plays an important role in cognitive development. Accordingly, age is associated with several changes in brain structure and function during this period (Galván, 2021). However, other developmental changes in the brain seem to occur at least partially independently of chronological age. These changes in the brain have been associated with the time course of the pubertal trajectory and include alterations in the patterns of brain activity and functional connectivity of several brain regions under varied conditions; these changes come accompanied by structural alterations, such as dramatic synaptic plasticity with a net loss of synapses in early adolescence (synaptic pruning), and a progressive increase in myelination until early adulthood; all these changes vary from region to region in the central nervous system and are associated with the development of different cognitive abilities (Baum et al., 2020; Faria Jr et al., 2021; Foulkes and Blakemore, 2018; Fuhrmann et al., 2015; Huttenlocher and Debholkar, 1997; Petanjek et al., 2011; Rakic et al., 1994; Whitaker et al., 2016).

Self-regulation of behavior during adolescence

Among the many cognitive changes occurring during adolescence, a particularly important set of alterations are those that affect the capacity to self-regulate behavior (henceforth, self-regulation). By self-regulation we mean the abilities that enable flexible, adaptive, and goal-directed control and/or regulation of behavior (Heatherton and Wagner, 2011; Hofmann et al., 2012; Nigg, 2017) on the basis of information that is in mind at a given moment – that is, in people's working memory. As such, self-regulation encompasses the capacities traditionally placed under the rubric of cool executive functions, which do not involve emotional or social stimuli and contexts (Baggeta and Alexander, 2016; Hofmann et al., 2012; Nigg, 2017; Zelazo and Müller, 2002). Examples are controlled attention, working memory, inhibition of automatic responses, updating, shifting, planning, dual tasking, and verbal fluency (Friedman & Miyake, 2017). Self-regulation also encompasses so-called hot executive skills, including the ability to regulate emotions and impulses under arousing and/or social conditions (Baggeta and Alexander, 2016; Hofmann et al., 2012; Nigg, 2017; Royall et al., 2002; von Bastian et al., 2020; Zelazo and Müller, 2002).

From its very definition, it is clear that self-regulation is essential for living a healthy and fulfilling life. Without this capacity, it is difficult to pursue goals while navigating the mosaic of contexts that constitute our lives. What is of particular interest in this field of work regarding adolescence is that self-regulation abilities involve different networks of brain regions that have different developmental trajectories, with some brain regions maturing earlier and others showing a protracted developmental course, with a lot of nonlinear trajectories (Casey, 2014; Casey et al., 2016; Ernst 2014; Ernst et al., 2006; Gracia-Trabuenca et al., 2021; Heatherton e Wagner, 2011; Icenogle and Cauffman, 2021; Shulman et al., 2016). Therefore, the precise developmental trajectory of self-regulation varies depending on the specific ability and/or the measures used to assess it.

There are three main sets of theoretical perspectives that explain adolescents' self-regulation maturation. The first set is the most prevailing and generally referred to as imbalance models, such as dual systems and the triadic model (for reviews, see Casey, 2015; Ernst, 2014; Ernst et al., 2006; Shulman et al., 2016). These models propose that, on the one hand, there seems to be an overall linear improvement in cool self-regulation from childhood to adulthood which accompanies the maturation of frontal regions of the brain (Crone, 2009; Crone and Steinbeis, 2017; Gabriel et al., 2019; Icenogle and Cauffman, 2021; Icenogle et al., 2019; Steinberg et al., 2008; Steinberg et al., 2017; Yurgelun-Todd, 2007). Furthermore, even in cases in which these abilities seem to reach adult levels during adolescence (e.g., Lantrip et al., 2015; Ogilvie et al., 2020), improvement with age is still observed in terms of the capacity to employ these skills in a more consistent manner (Constantinidis and Luna, 2019; Icenogle and Cauffman, 2021). On the other hand, these developmental models suggest a nonlinear developmental trajectory for hot self-regulation, which involves changes in socioemotional brain systems including the striatum and adjacent structures (Ernst, 2014; Shulman et al., 2016) associated with approach/reward behaviors, and the amygdala and adjacent structures (Ernst, 2014) associated with the regulation of avoidance behaviors. The trajectory of development of these networks is believed to follow an inverted u-shaped curve, peaking at some point in mid-adolescence (Casey, 2014; Casey et al., 2016; Heatherton e Wagner, 2011; Icenogle and Cauffman, 2021; Shulman et al., 2016). For this reason, many researchers argue that the imbalance or mismatch in developmental trajectories of control- and reward-related brain regions causes adolescents to have difficulties in restraining impulses and regulating emotion under arousing, motivational and/or social situations, predisposing them to reckless behavior (Icenogle and Cauffman, 2021; Shulman et al., 2016). Hence, immature cool self-regulation combined with hyper-responsive affective systems are widely believed to play a role in elevated risk-taking during adolescence (Heatherton and Wagner, 2010; Icenogle and Cauffman, 2021; Luna et al., 2015; Steinberg, 2008; Steinberg et al., 2017; Smith et al., 2013).

The perspective of hot self-regulation in the dual systems (Casey, 2015; Shulman et al., 2016) and the triadic (Ernst, 2014; Ernst et al., 2006) models involves a broad range of abilities regarding adolescents' self-regulation that are dissociable according to two other theoretical approaches [reviewed by Dafoe et al. (2015) and Romer et al. (2017); see also Box 1]. In summary, according to this second set of views, the outcome of decision-making does not only depend on the imbalance between immature cool self-regulation and heightened emotional response, but also on risk probabilities, prior life experience and opportunities to take risks in real life. For example, risky behaviors are only consistently found to be more prevalent in adolescents than in children and adults under conditions in which risk outcomes are uncertain or ambiguous (Romer et al., 2017). This type of decision-making involving a gamble, or decisions between a sure option with small gains versus an unpredictable risky option with larger gains. In adolescence, this is believed to be associated with a peak in sensation seeking followed by a decrease with age, which makes sense as this peak would support the exploration and learning that is crucial in this phase of life (see Romer et al., 2017). In other words, in adolescence, the expectation of reward can outweigh the risk of a less probable negative outcome, so that not only the probability of the outcomes but also the magnitude of the possible positive outcome can affect decision-making. This type of impulsive choice under uncertainty is also partly dependent on self-regulation abilities (analytical reasoning or avoiding acting without thinking) and categorical thinking (automatic gist - an intuitive feeling derived from accumulated previous experiences of what is the best course of action), both of which improve linearly with life experience, leading to high risk aversion in adulthood (Dafoe et al., 2015; Romer et al., 2017). Results differ, however, when decision outcomes are unambiguous, that is, when the possible outcomes are clearly defined. In this condition, adolescents take fewer risks than children, and this further decreases in adults (Dafoe et al., 2015; Romer et al., 2017). A particular case of decision-making with unambiguous outcomes is that of delay discounting, which measures the preference for smaller sooner rewards versus larger, more delayed rewards (e.g., delay discounting tasks), where there is no actual risk because possible choices have sure outcomes. Although this way of assessing impulsive choice decisions is often confused with risk taking, risk does not apply in these conditions and results from adolescent performance in these tasks are mixed (Scheres et al., 2014).

A third perspective on self-regulation maturation in adolescence focuses on social engagement (see Nelson et al., 2016), positing that the bottom-up salience to social relation cues, subserved by subcortical brain areas, decreases the functional activity of the frontal areas responsible for cool self-regulation in social tasks or conditions (Nelson et al., 2016). This vision fits within a general view of developmental changes in the salience of different stimuli (Nelson et al., 2014). This salience shifts across adolescence from parents (pre-puberty) to peers (during puberty) and then to romantic partners (post-puberty), purportedly due to changes in sex hormone concentrations and experience/learning, involving temporal and occipital areas implicated in sensory and perceptual social representations (Nelson et al., 2014; Nelson et al., 2016).

Lastly, some of these perspectives call attention to the fact that as adolescents age they are not only exposed to different risk opportunities and social expectations (e.g., to experiment with drugs), but also become more autonomous, which can affect their willingness to take risks and/or lead to a higher chance of taking risks in real life compared to children. Hence, adolescent behavior and choices can differ from that of children in real life scenarios compared with laboratory settings (Dafoe et al., 2015). Overall, according to Dafoe et al. (2015) and Romer et al. (2017), it is simplistic to claim that adolescence is a time of life in which impulsive choices, in general, are at a peak, which seems to be the underlying assumption of most developmental studies. Instead, the type of behavior, decision-making task (e.g., with or without risk and uncertainty) and type of assessment (laboratory tasks versus real life, the latter of which can be assessed with questionnaires) must be taken into account to draw a clear picture of cognitive maturation across adolescence.

While the relationship between self-regulation and impulsive/risky behavior is not always clear (see **Box 1** for further discussion of this issue and its implications for this review), self-regulation skills are decidedly necessary for reaching analytic, rational, non-emotional goals (cool self-regulation), and so are positively associated with important real-life outcomes like educational attainment, professional success, and wealth (e.g., Benjamin et al., 2020; Eisenberg et al., 2019; Moffitt et al., 2011). Furthermore, at least some self-regulation difficulties that involve emotion/social stimuli or contexts (hot) have also been found to be negatively associated with mental and physical health throughout life, such as self-reported poor emotional control and impulsivity (e.g., Benjamin et al., 2020; Eisenberg et al., 2019; Moffitt et al., 2011). Therefore, there is great interest in understanding how both cool and hot self-regulation mature during adolescence, a period that may provide an ideal window for intervention thanks to the pronounced plasticity of the brain in this phase of life (Dorn et al., 2019).

The development of self-regulation has been most commonly studied in relation to the individuals' age or related variables, such as school grade. The age variable is commonly used to represent general maturation and, in the context of cognitive development, it is also viewed as a proxy for the accumulation of life and academic experiences. Thus, age works as an aggregating variable in developmental research, loosely capturing the results of a wide range of developmental processes that take place as individuals grow older. But this variable does not allow us to disentangle the effects of these different developmental processes, and some of them may be more important than others. A particularly relevant process taking place during adolescence – and one that may have important effects on the development of self-regulation – is puberty.

Puberty and cognitive development during adolescence

Puberty is a process that involves a cascade of neuroendocrine events and alterations in several physical and physiological characteristics, leading to the attainment of reproductive capacity (Abreu and Kaiser, 2016; Lee and Styne, 2013; Witchel and Topaloglu, 2019). More specifically, puberty is characterized by the effects of increased production of androgens by the zona reticularis of the adrenal glands and a surge of gonadal sex hormones due to the activation of the hypothalamic-pituitary-gonadal axis. These adrenal and gonadal hormones then go on to induce, in concert with other hormones, a series of morphological and physiological changes, including growth in height, maturation of the gonads and the development of secondary sexual characteristics (DiVall and Radovick, 2009; Lewis and Lee, 2009; Wood et al., 2019).

Importantly, pubertal processes also seem to elicit structural and functional brain changes implicated in self-regulation (Casey, 2013; Casey and Caudle, 2013; Foulkes and Blakemore, 2018; Goddings et al., 2019; Gracia-Tabuenca et al., 2021; Juraska and Willing, 2016; Peper and Dahl, 2013). Animal studies even raise possible mechanisms behind the relationship between puberty and brain maturation, such as through the effects of estrogen on the inhibitory/excitatory balance in frontal brain regions (Piekarski et al., 2017) or through hormonal effects on the production of new brain cells during adolescence (Ahmed et al., 2008). However, in humans, many questions remain as to the precise contribution of the pubertal transition to changes in different brain regions during adolescence (Goddings et al., 2019) and their relation with behavioral and cognitive changes (Casey, 2015; Crone, 2009; Ernst, 2014; Ernst et al., 2006; Murty et al., 2016; Pfeifer and Allen, 2012; Smith et al., 2013; Yurgelun-Todd, 2007).

The available evidence suggests that, at any given moment during the life of an adolescent, his or her self-regulation ability may reflect not only their age, but also the stage of puberty they are in (i.e., their pubertal status). Crucially, pubertal status can vary significantly between same-aged peers because pubertal development varies widely between sexes and individuals – and, in some cases, among populations – in terms of the age when it begins (sometimes referred to as pubertal timing) and in terms of its developmental trajectory (pubertal tempo) (Dorn, 2006, 2015; Dorn and Biro, 2011; Dorn et al., 2006; Huang et al., 2009; Mendle et al., 2019). For example, it is considered normal that girls show the first physical signs (or enter puberty) between 8 and 13 years of age, while boys do so around the ages of 9 to 14 years; the total time taken to reach the end of puberty in both sexes also varies widely (Dorn and Biro, 2011; Dorn et al., 2006; Joos et al., 2018; Mendle et al., 2019), spanning from around two to six years (Joos et al., 2018), although most adolescents are regarded as pubertally mature at around the age 16 years (see Marceau et al., 2011).

The recognition of these inter-individual changes in terms of age of onset and end of puberty, which do not follow a linear trajectory, has contributed to the growing interest in exploring pubertal effects on cognition and behavior in the last few decades (Marceau et al., 2019). During this period, many recommendations have been proposed regarding ways to incorporate pubertal measures in developmental studies (Byrne et al., 2019; Cheng et al., 2021; Dorn, 2006, 2015; Dorn and Biro, 2011; Dorn et al., 2006; Huang et al., 2009; Mendle et al., 2019). However, conceptual difficulties remain. There are significant variations in the synchronicity of different puberty-induced changes, with only small-to-moderate correlations between different physical developmental makers such as pubic hair growth and breast/genital development, and lack of a clear match between physical changes and sex hormone concentrations (Dorn and Biro, 2011; Mendle, 2014; Mendle et al., 2019). Therefore, the choice of variables that can best represent each individual's pubertal status can be a difficult one.

Moreover, although both the above-mentioned dual-systems and the triadic models of cognitive development during adolescence consider that part of the changes in self-regulation are associated with puberty (e.g., Ernst, 2014; Ernst et al., 2006; Shulman et al., 2016), they do not explore this issue in depth and do not consider the impact of variability in pubertal onset and tempo in creating variability in performance within same-aged adolescents. Nonetheless, Ernst et al. (2006) and Shulman et al. (2014) suggest that the prefrontal changes that support cool self-regulation develop independently of pubertal status, while cognitive processes that involve hot, socioemotional networks are dependent on puberty, peaking in mid-adolescence, with a corresponding peak in reward-seeking, risk-taking behaviors (Shulman et al., 2016) which often corresponds to the end of puberty (Abreu and Kaiser, 2016; Witchel and Topaloglu, 2019). Differently, Dafoe et al.'s (2015) meta-analyses showed some support for higher general (hot) risk taking in early- (11-13-year-olds) compared to mid-adolescents (14-19-year-olds), suggesting that there are some negative early pubertal effects on hot self-regulation involving decision-making. These authors acknowledge, however, that this would have to be confirmed with actual measures of pubertal status as only one of the reviewed studies actually included pubertal variables. Furthermore, Dafoe et al. (2015) showed no difference between risk taking (combining many types of risk) in children and early adolescents and in children and adolescents in general (11-19-year-olds) except that, when choices between different sure-win options were involved, adolescents seemed to show better performance, and not worse decisions, associated with heightened emotional responses. Hence, further evidence of specific hot risk-taking/decision-making increases in early adolescents is needed. Overall, it can be said that some of the developmental models of self-regulation in adolescence imply that cool self-regulation improves with age/experience independently of pubertal status, while hot self-regulation may depend on the stage of puberty, possibly regardless of age.

Determining the relationship of puberty with hot self-regulation is a particularly thorny issue because of the difficulty in disentangling the effects of pubertal status from the effects of age, as both are correlated despite the large interindividual differences in terms of the age when puberty begins and in terms of its trajectory. Stated differently, older individuals tend to be, on average, more advanced in their pubertal development (Cheng et al., 2021) so the relation between pubertal status (stage of pubertal development) and self-regulation outcomes might merely index age effects (like, for example, improvements in self-regulation due to academic and life experience) and vice-versa. It is therefore paramount to understand whether and to what extent pubertal status affects adolescent ability to self-regulate behavior beyond the effects of their age, regarding both cool and hot skills.

Additionally, there is significant evidence in the literature suggesting that sex, ethnicity and socioeconomic status (SES) can influence both pubertal development and the development of self-regulation (e.g., Blum and Boyden, 2018; Hertliz et al., 2013; Mendle et al., 2019; Steinberg et al., 2017) so these factors should be considered and, ideally, be controlled/adjusted for when determining whether and to what extent pubertal status is associated with self-regulation.

These issues have implications for academic contexts and for policy-making. For example, the school system is based on the understanding that adolescents who are the same age should display comparable cognitive abilities, despite the fact that adolescents in the same grade can be at very different stages of puberty and thus differ in terms of their brain and cognitive maturation, and higher pubertal maturity has been found to be positively related with academic success (see, for example, Torvik et al., 2021). For the same reasons, policy making regarding adolescents could also profit from considering pubertal status beyond age in terms of maximizing preventive socio-educational measures to decrease adolescents' vulnerability, impulsive actions and risk taking, and improve their health and well-being, which involve improving self-regulation development, as well as building a fairer legal system regarding adolescents' rights, duties and accountability (Dorn et al., 2019; Galván, 2014).

The present study

In this scenario, our primary goal was to systematically review the literature to establish the state of the evidence regarding the association of pubertal *status* with behavioral self-regulation performance in typically developing adolescents (i.e., non-clinical samples). By pubertal status, we mean the stage of sexual development an individual was in at the time his or her self-regulation abilities were assessed. To put this differently, we were interested in establishing if and how self-regulation changes throughout pubertal development. Therefore, we review studies that concurrently assessed self-regulation and any indicator of pubertal status (be it physical characteristics or concentrations of substances like sex hormones) and that reported on their association.

Here we must raise three important points. First, because we were interested in the effects of pubertal status – the stage of development the individual is in –, we did not review studies reporting effects of relative pubertal timing (whether pubertal development is earlier or later compared to adolescents' same age peers, regardless of their actual pubertal status), such as studies that regressed any pubertal status variable on age and used the residuals for the analyses.

Second, we intended to describe the effects of pubertal status on self-regulation that cannot be attributed to differences in age, so we focused on studies that took into consideration the effects of age as a continuous variable (age in months or non-integer years) in the statistical analyses (see Cheng et al., 2021). This was done because there is extensive evidence that pubertal status can change within a period of one full year (for a clear illustration, see data in Gracia-Trabuenca et al., 2021) and that there are cognitive differences between older and younger individuals when age is counted in completed years, even within the same school grade (e.g., Peña, 2020). We elaborate further on these two points in the **Supplementary Text**.

Third, while we have a specific definition for self-regulation, there are many different (and sometimes conflicting) definitions in the literature. As a result, there are several available tasks and scales that measure self-regulation and related skills (Baggeta and Alexander, 2016; Chan et al., 2008; Nigg, 2017; Zelazo and Müller, 2002), with a many-to-many mapping between definitions and instruments and jingle-jangle fallacy issues (e.g., Packwood et al., 2011). This makes it difficult to determine what type of self-regulation is assessed with different measures based uniquely on how researches choose to describe them. Hence, we only review studies whose measures fit our definition of self-regulation (more details on this issue are provided in the Methods section).

Beyond exploring the available studies on the association between pubertal status and self-regulation, we also aimed to produce a critical appraisal of the literature. Thus, our secondary objective was to analyze this literature to understand how the characteristics of the available studies affect their reliability and generalizability. Therefore, we discuss the possible implications of study designs, sample characteristics, choice of pubertal and cognitive measures, the statistical models used, and possible unaccounted factors, among other issues.

In what follows, we present our approach to reviewing the literature and provide a critical account of our findings. As described in detail below, we found that most available studies reporting results on the relationship between measures of pubertal status and self-regulation did not adjust for age effects, or did so in a way that does not enable an adequate interpretation of the results in terms of pubertal status effects. We also show that available studies on the effects of pubertal status on self-regulation used a variety of different (and often difficult to compare) measures of pubertal status and self-regulation. These studies show inconsistent results with few clear patterns and their reliability is limited by a set of common methodological pitfalls ubiquitous in this and related fields. We conclude by providing suggestions for addressing these issues and improving the level of information in future studies.

Methods

For designing the review, we took guidance from Bramer et al. (2018), Cooper (1982), Jackson (1980), Gough et al. (2012), Higgs and Green (2008), Leenaars et al. (2012), and Siddaway et al. (2019). For reporting the review results, we followed the PRISMA 2020 guidelines whenever applicable (Page et al., 2021). Next, we will briefly describe the review process, highlighting changes to our original, preregistered protocol, which is available online (http://doi.org/10.17605/OSF.IO/URMBX). Additional information can be found on the project's page at the Open Science Framework (OSF; https://doi.org/10.17605/OSF.IO/XFNUZ).

Eligibility criteria

Our research question was: 'What is the effect of pubertal status on self-regulation of behavior in healthy, typically-developing adolescents?' To be relevant to our research question, studies needed to have certain characteristics in terms of their design, the population under study, and the measures employed. Specifically, we looked for studies with the following characteristics:

- **Study design:** We only included studies reporting original results. They could be either longitudinal or cross-sectional studies evaluating self-regulation during the pubertal transition.
- **Participants:** Studies had to be on human participants aged 10-19 years, following the definition of adolescence by the World Health Organization ("Health for the world's adolescence" report: World health organization, 2014). However, we did not fix rigid age limits – studies that also

included participants younger or older than our specified age range could be included, as long as the study dealt with our review question. Additionally, studies should focus on non-clinical samples to exclude the interference of clinical conditions that can influence self-regulation and/or pubertal development. Hence, we did not include studies focusing exclusively on clinical populations, such as with developmental disorders (e.g., attention deficit hyperactivity disorder, learning disabilities, and autism spectrum disorder), mental health problems, addiction, eating disorders, and pathological pubertal development (e.g., central or peripheral precocious or delayed puberty).

- **Measurements of pubertal status**: We only included in the review studies that employed at least one method to evaluate pubertal status [e.g., Tanner Stages, the Pubertal Development Scale (PDS), and/or hormonal assays (see Dorn and Biro, 2011; Dorn et al., 2006; Mendle et al., 2019)] measured around the time of cognitive assessment.
- **Measurements of self-regulation**: Studies should also report at least one suitable measure of self-regulation. Eligible measures of self-regulation could be either tasks or questionnaires/scales. These measures should assess outcomes directly related to self-regulation abilities. This criterion was relatively straightforward for tasks, and most of the tasks traditionally associated with behavioral self-regulation and executive functions were considered, excluding, however, measures that predominantly involve so-called crystallized intelligence (e.g., receptive vocabulary and general knowledge) because they assess cognitive abilities such as language and semantic memory, which are highly dependent on parental schooling (e.g., Cheadle, 2009) and academic experience and not *primarily* related with self-regulation as defined here. However, measures of fluid intelligence (e.g., block design and various forms of matrices tests) were considered as they are regarded as highly associated with cool self-regulation (Chan et al., 2008; Royall et al., 2002; Zelazo and Müller, 2002). Applying this criterion to questionnaires was more difficult because many of those that are traditionally associated with self-regulation do not fit our definition of this construct. For example, scales that investigate problem/risk-behaviors, reward sensitivity, and sensation seeking do not usually differentiate behaviors that were carried out due to self-regulation failures or due to actual choices made by adolescents. For instance, many scales regard drinking alcoholic beverages or enjoying radical sports in adolescence as self-regulation failures (acting out on impulse, or on a whim) without considering that individuals often can and do purposefully/deliberately choose to do so, in which case this behavior should not be considered a self-regulation failure (we provide further discussion about this issue in **Box 1)**. Based on this criterion, most included questionnaires were self-, parental- or teacher-reported hot and cool self-regulation failures/difficulties.
- **Analyses of the relationship between pubertal status and relevant outcomes**: For inclusion in the review, studies also had to report results on the statistical relationship between the measure

of pubertal status and the measure of self-regulation obtained in close proximity in time. This is important because we found many studies employing these measures but that did not report results on their relationship.

- **Controlling/adjusting for age effects**: Finally, studies had to control or adjust for the effects of age in such a way that results could be interpreted as reflecting the association (or lack thereof) of pubertal status and self-regulation that could not be explained by age-related self-regulation improvement. Age should be reported in years with at least one decimal point or in months because, as mentioned in the Introduction, both pubertal status and cognitive abilities advance within a one-year period during this phase of life.

Information sources and search strategy

To find relevant studies, we searched PubMed, Web of Science (Core Collection), Scopus, and PsycInfo (via APA). The search strings used in these databases were built around the two main concepts in our research question, namely 'puberty' and 'constructs related to self-regulation'. Building a sensitive search string for the concept of self-regulation was challenging, and to find relevant terms we consulted literature reviews (e.g., Baggeta and Alexander, 2016; Chan et al., 2008; Nigg, 2016; Zelazo and Müller, 2002), the thesaurus of PubMed and PsycInfo (APA), and had the input of field experts (SP and MCM). After several rounds of testing and evaluating search results for relevance, we ended up with the following list of terms:

- Concept #1 (puberty): Puberty; Pubertal.

- Concept #2 (self-regulation of behavior and executive functions): "self-regulation"; "self-control"; "behavio* control"; "behavio* regulation"; "regulation of behavio*"; "control of behavio*"; "executive function*"; "central executive"; "executive control"; "executive network"; "inhibitory control" ; cogniti*; "working memory"; intelligence; attention*; "decision-making"; "decision-making"; "academic achievement"; "academic success"; "emotion* regulation"; "emotion* control"; "regulation of emotion"; "control of emotion"; "theory of mind"; "facial recognition"; "facial expression*"; reward; "sensation seeking"; "risk taking"; "risk-taking"; impulsiv*; "impulse control"; "novelty seeking"; "novelty-seeking"; "delayed discounting"; "temporal discounting".

As already noted in the Introduction, there are conflicting definitions of self-regulation in the literature and the relationship between measures and concepts can be complex. For this reason, irrespective of the terminology used by the authors of the reviewed papers to describe which cognitive/behavioral ability was being tested, we opted to work with a broad range of measures that are usually associated with self-regulation (e.g., executive functions, controlled attention, inhibition, self-control, impulsiveness). Hence, the decision on whether or not to include the study in this review was carried out case-by-case during the evaluation of full-texts based on the description of the self-regulation tasks or questionnaires. We return to this issue in more detail when describing the criteria used to select these measures.

The search terms were used to build search strings according to the syntax of each search engine. The final search strings used for each engine are presented in **Table 1**. The searches were originally conducted in February 2020, and were last updated in February 2022. To look for grey literature, we contacted the authors of included studies via email asking for any additional studies they may have conducted on the topic, published or not[†]. The attempts to contact authors were made in January 2022. We also refrained from using filters for document types on the search engines to include any theses, dissertations, or congress/symposium-related publications indexed in the databases searched.

Study selection

The study selection was conducted in two stages. First, titles and abstracts were screened. In stage 2 we evaluated the full texts of studies that could not be eliminated with certainty based on consideration of the title and abstract. At both steps, every record/study was assessed by two investigators independently (TFAF and either SP, MCM, IAS, NMD, or one of two trained research assistants). During study selection, we used the following inclusion criteria, assessed in this particular order:

1. Report original empirical results;
2. Report data for non-clinical populations assessed at any age between 10 and 19 years (although this age range was flexible, as discussed above);
3. Use of at least one measure of pubertal status as defined above;
4. Use of at least one cognitive/behavioral measure of self-regulation as conceptualized based on the literature described in the Introduction;
5. Report results regarding the statistical relationship between pubertal measures and cognitive outcomes of interest;
6. Report results that are interpretable in terms of the direct association of pubertal status and self-regulation abilities. This implied that these measures had to be obtained in close proximity in time and had to be controlled/adjusted for age effects in a way that did not affect the interpretation of pubertal variables (i.e., not creating new variables with different meanings as happens in studies focusing relative pubertal timing; see the **Supplementary text**). Of note, this criterion was only evaluated at the second stage of study selection.

[†]We originally intended to search the OpenGrey database as well. However, preliminary searches on this database, conducted on May 2021 using the same search terms for other databases, returned only 14 results, none of them relevant for the review. Moreover, OpenGrey is being discontinued. Therefore, we opted to exclude this database from the review.

Criteria #5 and #6 on the list above were not originally made explicit in the registered protocol but were added here because our primary objective of investigating the relationship between pubertal status and self-regulation could only be reached if these precepts were kept. Without these criteria we would have ended up with studies that measured pubertal status and self-regulation but did not report their association, or studies that measured them at different times, and/or converted pubertal status measures into measures of relative pubertal timing, which do not speak to their direct relationship (see the **Supplementary Text** for further discussion of these studies). Whenever there was a disagreement during the first stage of study selection, the study in question was automatically approved to the second selection stage and its full text was evaluated. Disagreements in the second stage were decided by consensus between SP, MCM, and TFAF.

Data extraction and management

Relevant data from the included studies were extracted by TFAF and inserted into spreadsheets. We extracted the following data:

- Year of publication;
- Type of document;
- Goal of the study;
- Study design;
- Sample size;
- Participant information – age, sex, ethnicity, school grade, socioeconomic status, country/region of origin;
- Pubertal measure;
- Outcome of interest;
- Approach to adjust results for age effects;
- Summary of findings and statistics of interest.

Criteria for study evaluation

As noted in the Introduction, one of our goals was to provide a critical evaluation of the literature and of how the characteristics of the available studies affected the internal and external validity of their findings. To guide the critical evaluation of the literature we adapted a set of relevant questions from the Critical Appraisal Skills Programme (CASP) checklist for cohort studies, section A ("are the results valid?"; available online at <https://casp-uk.net/casp-tools-checklists/>), adding some criteria taken from the Joanna Briggs Institute Critical Appraisal Checklist for Analytical Cross Sectional Studies (available at <https://jbi.global/critical-appraisal-tools>). From this adaptation came the first version of the checklist, which is detailed in a document that can be found in the project's page at the OSF (https://doi.org/10.17605/OSF.IO/XFNUZ). The items of this initial version were refined and reorganized as we interacted with the studies themselves, leading to the final version described below.

The checklist was designed to ensure that the following points received systematic attention when interpreting the findings from this literature, as they can influence the internal and/or external validity of the studies:

- Was the study design (longitudinal, cross-sectional) appropriate to assess the role of pubertal status on self-regulation?
- What are the characteristics of the sample and can they affect the generality of the findings (external validity)?
- Were the pubertal measures informative to our goal of evaluating the effect of pubertal status on self-regulation development?
- Were the cognitive measures informative to our goal of evaluating the effect of pubertal status on self-regulation development?
- Were there any unaccounted factors (such as differences in age, sex, socioeconomic status, ethnicity, etc.) that could raise doubt about the conclusions (internal validity)?
- Related to the item above: a) were the statistical analyses appropriate and did they match the conclusions regarding the impact of pubertal status on self-regulation?; and b) what are the implications of the statistical assumptions to the significance of the reported statistics in the context of our review question?

Of note, this checklist was not used to provide a score for studies, nor to classify or to include/exclude them in/from this review. Rather, it was meant as a tool to help make a more systematic critical evaluation of the findings. The checklist helped to ensure that all relevant points listed here were taken into account when interpreting the literature, enabling the assessment of the strengths and limitations of these studies, as well as the susceptibility of their results to biases. Importantly, it should be noted that the items above are not yes-or-no questions and their answers go beyond simple assessments of a high or low risk of bias. When we reflected about the measures used, the characteristics of the studied populations, or the models used to analyze data, there are multiple possible answers, and different answers have different potential implications for what each study can tell us regarding our research inquiry. Moreover, most of the limitations found when evaluating the literature were common to most studies. Therefore, we opted to discuss the items in our checklist in a general way, assessing their implications for the whole literature instead of focusing on individual studies. The Discussion section includes our evaluation of each of the points listed above, and their implications to the interpretation of results from the reviewed literature.

Results

Search results and study selection and classification

Reference lists for the total search results, for studies approved in the first stage, and studies excluded by each criterion in the second stage of study selection, as well as for included studies, can be found in the project's page at the OSF (https://doi.org/10.17605/OSF.IO/XFNUZ).

Our searches returned a total of 12,646 records. A flow diagram summarizing the results of the study selection can be found in **Figure 1**. After removing duplicates and applying the first five inclusion criteria to titles and abstracts, and then to the selected full texts, we were left with a total of 113 studies that reported results on the concomitant relationship between pubertal status and an outcome of interest. Among these studies, however, data of the majority (n=86) were not considered here because they did not allow inferences to be made about the direct association (or lack thereof) of pubertal status itself and self-regulation corrected for age. Of note, this exclusion has no bearing on the quality of the studies. It only means that their goals did not exactly align with our review question. These studies fail to address our research questions either because they: 1) did not include chronological age in the statistical analyses nor controlled for it in the study design; 2) adjusted or controlled for age in a way in which scores did not reflect the participants' pubertal status *per se*. For example, by using measures commonly referred to as "(relative) pubertal timing" (Dorn and Biro, 2011; Dorn et al., 2006; Mendle et al., 2019), usually obtained by regressing an indicator of pubertal status on the participant's age and then using the residuals as the independent variable for further analyses. This type of measure only reflects how advanced or delayed in sexual development each individual is compared to age and sex matched peers, so that participants of different pubertal status can receive the same relative pubertal timing score; and/or 3) did not collect data on pubertal status and self-regulation performance in close proximity in time, that is, reported prospective cognitive effects of maturing earlier or later than peers. The reason for this was that, due to inter-individual differences in pubertal tempo, this type of study does not index pubertal status *at the time* of self-regulation assessment, even if the analyses adjusted for age effects. All these three factors precluded the possibility of these studies answering our research question, as they make it impossible to interpret results in terms of the relationship between pubertal status and self-regulation abilities. These issues are discussed in more detail in the **Supplementary text**, and more information about the studies excluded for the reasons above can be found in **Table S1** in the **Supplementary tables**.

The net result was that only a minority of these reports (n=27) were included in our review. Among these, there were two publications reporting the same results on the same sample: a paper (Herlitz et al., 2013) and a dissertation (Lovén, 2012). Two other studies, Koch et al. (2020) and Mendle et al. (2020), seem to have used the same sample, but they report results from different measures. Thus, we had a total of 27 reports, based on 26 studies and involving 25 datasets, included in the review. The studies were published between 1985 and 2022 (although all but two studies were published after 2001, and a total of 19 studies were published after 2010). These publications will be the focus of the rest of the review. They are summarized in **Table 2** and further detailed in **Table S2** in the **Supplementary Tables** file**.**

Characteristics of included studies

Design

Only four of the 27 studies reported longitudinal analyses involving measures of interest to the review (Chaku and Hoyt, 2019; Davison and Susman, 2001; Mathias et al., 2016; Ng-Night et al., 2016). Another two studies were also longitudinal (Koch et al., 2020; Waber et al., 1985), but all of the analyses of interest reported were cross-sectional comparisons. All other studies used cross-sectional designs. We stress that most of the studies were on relatively small samples, with only seven studies having samples with more than 200 participants.

Sample characteristics

All but five studies involved participants from the United States. The exceptions were a two studies with participants from Germany (Laube et al., 2020; Vetter et al., 2013), one with participants from the United Kingdom (Ng-Night et al., 2016), one with participants from Sweden (Herlitz et al. 2013/Lovén, 2012), and a study involving participants from multiple countries (Icenogle et al., 2017). Seventeen of the 26 studies involved samples with both male and female participants, the remainder having tested only male (n=3) or only female participants (n=6). As can be seen in Table 2, all studies reported information on the participants' ages, either as age ranges or mean and standard deviations, and sometimes both. Based on these data, we can see that most studies focused on early- and mid-adolescents (which makes sense as this is when the pubertal transition takes place) and only two studies had samples well into late-adolescence/early adulthood (Olson et al., 2008, and Sullivan et al., 2016).

Across studies that reported participants' ethnicity/race (n=21), the vast majority of participants were classified as being White. Only a few studies had a majority of non-White participants (Kretch and Harden, 2014; Steinberg et al., 2008; and, likely Icenogle et al., 2017, a cross-cultural study in which adolescents reflected the dominant ethnicity of their country). As for participant's SES, this variable was not reported in almost half of the studies. Among those that did provide data on SES (n=14), there was a mix of metrics that were often difficult to compare. Nonetheless, apart from the studies by Deater-Deckard et al. (2019) and Kretch and Harden (2014), most studies reporting SES seem to have included a majority of participants from middle to upper-class families.

Measures of pubertal status

The most common measure of pubertal status used in the eligible studies was the Pubertal Development Scale (PSD; Carskadon and Acebo, 1993; Petersen et al., 1988) or adapted versions, which were used by a total of 15 studies. This is a self- or parent-reported questionnaire with items that enquire about perceived adrenal and gonadal pubertal changes in skin, height and armpit hair (for both sexes), breast growth and occurrence of menarche (for females), and facial hair growth and voice changes (for males). Each item is scored on a 4 point-scale (1: has not yet started; 4: seems complete), except for the item in respect of menarche, with either 1 or 4 points scored for not having or having experienced menarche, respectively. Total scores are usually the average or the sum of the scores of the five questions. Eight studies measured pubertal status using Tanner stages (Marshall and Tanner, 1970, 1969), mostly assessed by a nurse or physician. This method assigns adolescents to one of five possible Tanner stages (from pre- to post-pubertal) based on pubic hair in both sexes and breast development in females or genital development in males. Additionally, there were nine studies that measured blood or salivary concentrations of sex hormones (together with the PDS or Tanner stages: n=7; or only these hormonal measures: n=2).

Measures of self-regulation

Most studies included only a single measure to assess cognitive abilities related to our operational definition of the concept of hot and cool self-regulation. These measures varied widely among studies and included a set of highly heterogeneous tasks and questionnaires. Various studies assessed some traditional (non-emotional/social) executive function tasks, which are commonly associated with control of attention, but each type of ability was generally represented by only one or two tasks (e.g., tasks for verbal fluency, mental rotation, working memory updating, continuous performance/sustained attention tasks, inhibition or inhibitory control). The most commonly investigated construct was “inhibition” or “inhibitory control”, loosely defined as the capacity to inhibit automatic, habitual and inappropriate responses. The case of inhibition provides a stark illustration of the heterogeneity of the instruments used by different studies, as there was significant heterogeneity among instruments that are supposed to measure this very construct. For example, among the laboratory tasks used to measure this construct there were a range of tasks, including the Flanker task, the anti-saccade task, the Stroop test, and the Go/No-go test, which reflect self-regulation skills in non-emotional/social conditions (cool).

In the laboratory, decision-making under socioemotionally salient conditions was also assessed in a few studies that used different intertemporal choice paradigms (delay discounting tasks with rewards) and decision-making under risk/uncertainty (e.g., the Iowa Gambling Task, the Airport Auction Task, and the Stoplight Game).

Heterogeneity was also observed in the assessment of self-regulation abilities using questionnaires that measure, according to the authors, constructs such as “inhibition”, “attention”, “self-control”, “emotion regulation”, etc., which are terms that can only be very loosely defined based on their use across studies. A careful analysis of the content of the questions or statements in the instruments used led us to classify them as (mainly) socioemotionally independent (cool) or not (hot). Hence, “cooler” measures about self-regulation difficulties in adolescents’ lives included scales such as the Brief Self-

Control Scale (BSCS) and the Effortful Control subscale of the Early Adolescent Temperament Questionnaire – Revised (EATQ-R). As for daily difficulties associated with self-regulation in socioemotionally salient conditions, a greater variety of measures were used, including scales (Social Skills Rating System [SSRS], Ruminative Response Scale of the Children's Response Styles Questionnaire, the Negative Urgency subscale from the UPPS-P, the Impulsive Behavior Scale for Children) and a single task that was used to explore social cognition/theory of mind (a story comprehension task).

Accounting for age effects and other putative confounders

Among the studies included in the present review, only Chaku and Hoyt (2019) took steps to control for age differences in the study design. This was a longitudinal study where all participants were assessed at the same age in each wave. All the remaining studies adjusted for age effects in the statistical analyses. This was done by adding age as a covariate in the statistical models (e.g., analyses of covariance [ANCOVAs], multiple regressions, or structural equation models). As for other possible confounders, most studies analyzed in this review did not adjust statistical analyses for SES or ethnicity/race, so these effects will only be mentioned when these studies are described below.

Summary description of studies' findings

Overall, nine of the 26 eligible studies found no statistically significant effects of pubertal status on outcomes measures of self-regulation after controlling/adjusting for age. As for the remaining studies, there were usually a few significant effects among an equal or greater number of non-significant results. Overall, the statistically significant results reported were effects of small-to-medium size, though some studies did not report effect sizes and often the precision of reported effect sizes could not be properly assessed based on the reported statistics (e.g., estimates reported without confidence intervals). As can be seen below, both positive and negative pubertal effects on self-regulation abilities were reported. The results from the studies are summarized in Table 2 and detailed in **Table S2** available at the project's page at the OSF site (https://doi.org/10.17605/OSF.IO/XFNUZ). In the following section, we briefly describe the results reported in this literature. Of note, while all studies measured aspects of self-regulation, not all instruments are directly comparable and a classification of the results was necessary for a coherent analysis/synthesis. Such classification, however, was not straightforward because: 1) there is not established consensual list of the types of cognitive abilities under the umbrella-term of self-regulation; 2) many studies named the assessed abilities with a mixture of terminologies, at times calling the same measure by different names, or different abilities by the same name (jingle-jangle fallacies); and 3) a variety of self-regulation abilities were sampled and many possible self-regulation domains were not at all represented in the selected studies. Based on a careful analysis of the description of the tasks and questionnaires reported in this literature, and taking into account our working definition of self-regulation, we divided the studies in three recognizable categories as follows: A) decision-making laboratory tasks, which mostly assess hot skills; B) self-regulation in real-life scenarios assessed with questionnaires that inquire about both hot and cool abilities; and C) classic laboratory tasks associated with cool self-regulation abilities, such as executive functions, working memory, and attention. We drew from the theoretical perspectives reviewed by Dafoe et al. (2015) and Romer et al. (2017) to categorize and sub-categorize self-regulation measures considering the presence of risks versus sure gains, and laboratory versus real life measures, and also attempting to separate hot self-regulation skills from cool abilities. For each of these three categories we initially summarized the findings and then detailed the results, as described next.

A. *Decision-making in laboratory tasks*

The seven studies in this category involved decision-making tasks of two main sub-types: decision-making under risk/uncertainty and intertemporal choice tasks that involved rewards (choices with sure win options), all of which are usually regarded as measures of hot self-regulation abilities.

i. Decision-making in laboratory tasks under risks/uncertainty

Four studies assessed decision-making involving risks and gains: Kretch and Harden (2014), Cardoos et al. (2017), Stenberg et al. (2008) and Icenogle et al. (2019). The results reported, however, were inconsistent. While the studies by Kretch and Harden (2014) and Cardoos et al. (2017) found negative effects of pubertal status on task performance, the studies by Steinberg et al. (2008) and Icenogle et al. (2019) reported positive effects, as detailed below.

Cardoos et al. (2017) in a sample of female adolescents found a negative effect of PDS scores and testosterone concentrations on performance in the Airport Auction task, which involves taking financial risks with virtual money to win the game and gain social status (having their photo shown to other players). Higher PDS scores and testosterone levels were associated with higher overbidding (willingness to wager above a neutral risk bid) and lower final earnings after adjusting for age, SES and vocabulary. In contrast, Icenogle et al. (2017) studied adolescents from both sexes and reported a positive effect of pubertal status on some of the analyzed aspects of adolescent performance in the Iowa Gambling task. This task involves maximizing winnings by choosing cards from different decks that unpredictably differ in the balance between reward and penalty cards; however, some decks lead to higher gains but also higher losses, leading to longer term smaller payouts so must be avoided despite providing some much higher gains. Performance was adjusted for age, sex, SES, and intelligence (measured by the matrix reasoning sub-test of the Wechsler Abbreviated Scale of Intelligence).

Steinberg et al. (2008) and Kretch and Harden (2014) both studied samples including male and female adolescents and investigated the relationship between pubertal development and behavior in a simulated driving task, the Stoplight game, using different scores. This task involves uncertain outcomes (timing of traffic lights at intersections and probability of crashes) under which players must decide whether to avoid risks (brake to stop at a yellow light, which results in losing time/points until the traffic light returns to green), take a small risk with a low pay off or opt to take a high risk with high payoff (e.g., going through a yellow light, which can save time/gain points but can lead to a crash/loss of points). Participants in Steinberg et al. (2008) were told they would receive monetary rewards depending on their performance, while Kretch and Harden (2014) had them carry out the task alone and watched by peers, with no apparent financial reward for their performance. Steinberg et al. (2008) found that pubertal status was not related to safe stopping, risky driving, or crashing, but that higher pubertal status indicators were associated with better performance (a higher number of successful intersection crossings) after adjusting for intelligence (assessed using the vocabulary and matrix reasoning subtests of the Wechsler Abbreviated Scale of Intelligence), SES, and age. Kretch and Harden (2014), on the other hand, found the opposite pubertal effect: more pubertally mature individuals (based on a gonadal score derived from a subset of items from the PDS) made a greater percentage of risky choices irrespective of carrying out the task alone or watched by peers. Their model was controlled for age, phonological working memory (assessed using a digit span test), sex, and ethnicity.

ii. decision-making involving choices between sure-win options

Six studies reported pubertal effects on delay discounting measures, all of which seemed to have employed hypothetical rewards and delays, meaning participants were expected to imagine their preferences if given a choice between waiting longer to get a bigger reward or receiving a smaller reward sooner. The exception was the study of Mathias et al. (2016), whose paradigm involved actually waiting for rewards, although whether rewards were virtual (points) or real (e.g., money) is unclear. Three of these studies showed fairly consistent negative pubertal effects (Laube et al., 2017, 2020; Mathias et al., 2016), with more pubertally advanced participants preferring immediate, smaller rewards. However, the three other studies found no pubertal effects: Olson et al. (2009), Sullivan et al. (2016), and Lee and Rasmussen (2022).

Laube et al. (2017) studied a sample of male adolescents. They built statistical models relating the proportion of smaller sooner choices in an intertemporal choice task to testosterone levels, age, and different task conditions (either between an immediate vs. larger later reward; or two delayed choices with delay, where the larger delay was associated with higher reward). They found an effect of the condition and testosterone interaction, with individuals with higher testosterone levels preferring smaller immediate reward choices. Laube et al. (2017) also fitted a model of temporal-discounting behavior with two key-parameters: the discount rate, k, and the parameter s, which represented the relative sensitivity to more immediate versus later rewards. The only significant result found was a positive, age-adjusted correlation between the parameter s and testosterone concentrations.

Laube et al. (2020) used the same measures as the one employed in the study by Laube et al. (2017), and fitted another delay discounting model to data from another set of male adolescents. They tried to predict the level of bias for the smaller sooner options and the parameter k based on both testosterone concentrations and age. The only effect found was that adolescents who had higher levels of testosterone also showed an increased response bias to the smaller sooner option.

Mathias et al. (2016) employed a longitudinal design that collected data on male adolescent participants at six months intervals for 3-4 years. The authors examined the effect of pubertal trajectory on the longitudinal change in performance during a computerized delay discounting task (called the Two Choice Impulsivity Paradigm, in which delays are experienced). Participants were classified in groups based on their longitudinal pubertal trajectory. The groups were termed Earlier (which had the highest PDS scores at all times), Later (which had the lowest PDS scores, gradually increasing at a tempo similar to the Earlier group), and Compressed (which started with PDS scores between the Earlier and Later groups, but had the largest increases in pubertal maturation over time). The full model included the continuous impulsivity scores as the dependent variables and age at study entry, verbal intelligence (measured with the Wechsler Abbreviated Scale of Intelligence), wave of measurement and pubertal group as the explanatory variables. They found that, on average, the Compressed group chose a significantly higher proportion of smaller and more immediate rewards than the Earlier group, but this difference was not statistically different to performance of the Later group.

Contrary to the three studies above, Olson et al. (2009), Sullivan et al. (2016), and Lee and Rasmussen (2022) found no pubertal effects on delay discounting measures. Both Olson et al. (2009) and Sullivan et al. (2016) tested male and female adolescents with delay discounting tasks and investigated the association between PDS scores and discounting variables corrected for age, finding no significant relationships. Lee and Rasmussen (2022) applied two variations of delay discounting questionnaires to adolescents of both sexes, a traditional one with monetary rewards and a variation with food rewards. The authors investigated the relationship between Tanner stages and the discount variable of a delay discounting model adjusting for age and body mass index/percentage of body fat, reporting no associations.

B. *Self-regulation difficulties in real-life scenarios (assessed with questionnaires)*

The studies that assessed self-regulation in real-life employed questionnaires/scales which could be further separated into: i) questionnaires involving self-regulation difficulties mostly under socioemotional scenarios (hot); and ii) questionnaires that enquired about these difficulties in mostly socioemotional neutral conditions (cool).

i. Self-regulation in socioemotional contexts (hot)

Overall, small negative effects of pubertal status were found on self-reported self-control difficulties using different questionnaires/scales that inquire about adolescents' behavior in socioemotional salient (hot) conditions in their daily lives (Chaku and Hoyt, 2019; Koch et al., 2020; Mendle et al. 2020; Ng-Night et al., 2016; Vetter et al., 2013; Warren and Brooks-Gunn, 1989), although the effects, when reported, were only consistently present in females in early puberty (Chaku and Hoyt, 2019; Ng-Night et al., 2016; Warren and Brooks-Gunn, 1989), who had more difficulties in self-regulating in these conditions. However, results from Vannucci et al. (2014) and Vetter et al. (2013), as well as part of the results from Mendle et al. (2020), showed no pubertal effects on three of such measures. Chaku and Hoyt (2019) conducted a seven year-long longitudinal study assessing participants Tanner stages and self-control (using a subscale of the Social Skills Rating System) at exactly the same ages, thus controlling for age differences in the design of the study. Among females, but not males, they found that pubertal status at baseline was negatively associated with initial self-control in socioemotional settings (e.g., responding to teasing, peer pressure and controlling temper) adjusting for sex, ethnicity and baseline SES. Despite this, there were no longitudinal associations between pubertal development and self-control.

Ng-Night et al. (2016) collected data on pubertal status (using the PDS) and hot self-control (using the Brief Self-Control Scale, which the participant's ability to resist temptations, control bad habits and avoid doing things they might later regret) in a longitudinal study with three waves of data collection, each six months apart. The authors built a large structural equation model including parenting style measures, pubertal status and hot self-control, adjusting for sex, age, parental education, and total difficulties (assessed using the Strengths and Difficulties Questionnaire). Their analyses showed that more advanced pubertal status at baseline was associated with lower scores at baseline, similarly to Chaku and Hoyt (2019), but in this case the effect was found in both sexes.

Warren and Brooks-Gunn (1989) reported a similar finding but again only in females. While adjusting for age, the authors found a quadratic (but not linear) association of Tanner stages and blood concentrations of different sex hormones with scores on the Impulse Control subscale of the Self-image Questionnaire for Young Adolescents, a questionnaire that assesses hot self-regulation in the form of the capacity to control impulses under arousing conditions. Specifically, there was a decreased trend in impulse control during early puberty, followed by an improvement from mid- to late-puberty.

Koch et al. (2020) did not show this same hot self-regulation difficulties in early puberty but, instead, found that self-reported failures in regulating rumination increases throughout puberty (assessed using the PDS) in a sample of female adolescents. The same results were found by Mendle et al. (2020), who seems to have used largely the same sample as Koch et al. (2020). Mendle et al. (2020) also reported no significant effects of pubertal status on impulsivity when in a state of negative affect (negative urgency), assessed with the UPPS-P scale (again, only females were assessed).

Vannucci et al. (2014) also failed to find significant effects of pubertal status on a measure of self-reported loss-of-control eating in either male or female adolescents, and the single study that assessed social cognition (theory of mind on a story comprehension task), found no pubertal effects either (Vetter et al., 2013).

ii. Self-regulation in socioemotional-neutral contexts (cool)

Three studies used this type of measure. No relation of pubertal status adjusted for age was found in scores in questionnaires that assessed cool controlled/effortful self-regulation, not associated with socioemotional context (e.g., difficulty sitting still, concentrating, shifting among activities and persevering), assessed by parents using the Attention Subscale of the Child-Behavioral Check List (CBCL) (Chaku and Hoyt, 2019) and the 5-item Attention Scale from the Youth Self-Report Questionnaire (Graber et al., 2006). There was one exception: a small decrease in performance was found in females as they became more sexually mature (Ellis, 2002).

The dissertation by Ellis (2002) reports small negative partial correlations (adjusting for age) between pubertal status in females (measured with the PDS) and overall self- and parent-reported activation control, attention, and inhibition sub-scores of the Effortful Control sub-scale of the Early Adolescent Temperament Questionnaire-Revised, but showed no effects in males.

C. Classic laboratory tasks associated with cool self-regulation abilities (e.g., executive functions, working memory, attention)

The remaining selected studies assessed cool self-regulation abilities that can be categorized under the rubric of cool executive functions and associated working memory and attention using laboratory tasks that do not involve socioemotional contexts or arousing stimuli. With two exceptions discussed below, most of these abilities were assessed in only one or two studies, none of which were found to relate to pubertal status adjusted for age. This was the case for abilities such as verbal fluency (assessed in two datasets: Herlitz et al., 2013/Lovén, 2012; Waber et al., 1985), as well as speed and accuracy of composite scores of working memory updating (composite of various measures of a visual N-back task), and sustained attention (composite including various measures of a continuous performance task) obtained from the University of Pennsylvania Web-Based Computerized Neurocognitive Battery–WebCNP (Sullivan et al., 2016). However, there were two domains of these abilities that were tested in more than a couple of studies, albeit with vastly different tasks/scores: inhibition of automatic responses and visuospatial working memory abilities, the former having shown mostly no effects (consistent lack of pubertal status effects corrected for age), while for the latter there were mixed results across puberty adjusting for age, mainly in males, as detailed next.

i. Inhibition of automatic responses

Six studies investigated inhibition measures. No pubertal effects adjusted for age were reported with any of the tasks used (Multisource Interference task: Deater-Deckard et al., 2019; Antisaccade task: Ordaz et al., 2018; Go/No-go task: Gorday and Meyer, 2018; the Immediate Memory task and the GoStop

Impulsivity Paradigm: Mathias et al., 2016; Stroop Color-Word Interference: Waber et al., 1985). The only exception to the lack of pubertal effects corrected for age was the study by Castagna and Crawley (2021), who analyzed the parameters of two different decision models fitted to data from the inhibition flanker task and found a very small, negative effect of the interaction between sex and PDS scores on a parameter representing the amount of information that is considered for a decision. A follow-up analysis of these interactions showed this effect to be present only in females, who needed less information, or became less conservative in making their response as they matured.

ii. Visuospatial working memory abilities

Four datasets were used to investigate spatial working memory. Age-adjusted pubertal effects were mixed, with positive effects (Davison and Susman, 2001; Herlitz et al., 2013/Lovén2012), mainly in males, as well as negative effect (Waber et al., 1985), and one report of no effects (Sullivan et al., 2016).

Herlitz et al. (2013)/ Lovén (2012) found a positive partial correlation, adjusting for age, between scores in a mental rotation task and estradiol concentrations in males but not in females, with more sexually mature males having better performance. Similar results were reported by Davison and Susman (2001), who carried out cross-sectional analyses using data from three waves of a longitudinal study (each six months apart). They looked at the correlation between sex, hormonal levels and different measures of spatial abilities involving working memory, analyzing data for males and females separately. There was a mix of positive and null results. Cross-sectional analyses showed that in some waves there were positive correlations between mental rotation and testosterone for female participants. For male participants, there were positive correlations between testosterone levels and mental rotation scores, and between both testosterone and estradiol levels and scores in the block design task. The study also reported a longitudinal linear association between testosterone levels and mental rotation/block design for males, but not females.

In contrast, Waber et al. (1985) reported a significant age-adjusted *negative* correlation between both coding and block design scores and Tanner stages in female participants, but found no association in males. However, this effect could only be found when separately analyzing data for participants from one of the two study towns and should be considered with caution. Finally, Sullivan et al. (2016) reported no association of PDS scores in either sex with composite speed and accuracy score of tasks involving abstraction and visuospatial reasoning from the WebCNP, including a flexibility conditional visuospatial exclusion task, akin to the Wisconsin Card Sorting task, as well a matrix task and a logical reasoning task.

A glance at the whole picture

The results reviewed in the previous sections highlight the significant heterogeneity of findings reported in this literature. However, a look at the information listed in **Table 2,** and a careful evaluation of the study details listed in the supplementary **Table S2**, shows that results are even more heterogeneous than they seem from the descriptions made above because various details regarding the analysis of experimental data in each study were omitted for the sake of creating a readable summary. Moreover, publications were categorized into types of self-regulation based on our reading of which aspects of self-regulation were assessed in the tasks and questionnaires used in the reviewed literature.

However, most types of tested self-regulation abilities were assessed in only one or a small set of studies, and in the cases in which more than one study assessed the same type of ability the tasks/questionnaires/scores that were used often differed between studies. The results were rife with inconsistencies regarding the existence and direction of pubertal effects, as detailed in the Discussion. In most cases in which significant associations were found between age-corrected pubertal status and self-regulation abilities related to either hot or cool self-regulation, assessed with either tasks or questionnaires in the laboratory or pertaining to real-life self-regulation, there were corresponding studies that assessed the same or similar self-regulation constructs and did not find statistically significant associations, or even found associations in the opposite direction.

There were only two (seemingly) consistent findings when more than a couple of studies assessed comparable abilities. The first was a lack of pubertal effects controlled for age in studies measuring cool abilities with tasks (Chaku and Hoyt, 2019; Graber et al., 2006; Sullivan et al., 2016; but see Ellis, 2002), including those relating to inhibition (Deater-Deckard et al., 2019; Gorday and Meyer, 2018; Mathias et al., 2016; Ordaz et al., 2018; Waber et al., 1985; but see Castagna and Crawley, 2021) and questionnaires (Chaku and Hoyt, 2019; Graber et al., 2006; except for a very small effect in females only: Ellis, 2002). A second, and most notable, apparently consistent effect was that more advanced pubertal indicators were related to more self-regulation difficulties assessed using questionnaires that assess real-life behavior in socioemotional contexts (hot), an effect that was consistently present, but only in females in early-puberty (Chaku and Hoyt, 2019; Ellis, 2002; Koch et al. 2020/Mendle et al., 2020; Ng-Night et al., 2016; Warren and Brooks-Gunn, 1989). Moreover, even in this case the consistency was not perfect because Vannucci et al. (2014) found no effects of pubertal status on a measure of self-reported loss-of-control eating using a sample that included both male and female 8 to 17 year-olds. Additionally, Mendle et al. (2020) reported no significant effects of pubertal status on impulsivity when in states of negative affect (negative urgency), while rumination (i.e., failure to control persistent negative thoughts) was found to increase progressively throughout puberty in females (Koch et al., 2020/Mendle et al., 2020).

Discussion

Our primary goal in this systematic review was to establish the state of the evidence regarding the association of pubertal status with behavioral self-regulation performance in adolescents. The overall picture that emerges from our review, however, is that of a literature rich in data but poor in reliable answers. Importantly, because of the confounding effects of age, which is associated with both pubertal status and self-regulation, we looked for studies that controlled or adjusted for age effects – and that did so without altering the nature of the pubertal status variable. This is a necessary condition to interpret results in terms of pubertal status effects. However, for varied reasons, most of the literature did not meet this criterion. In fact, we found a total of 113 studies reporting statistical results on the relationship between pubertal status and self-regulation, but 86 of those were not interpretable in the context of our research question, and almost all interpretation issues were caused by either not controlling/adjusting for age effects or doing so in an insufficient/inappropriate way to provide information on pubertal status effects – either because the adjustment was not sufficiently fine-grained or because it fundamentally altered the pubertal variables, as discussed below.

This meant that we were left with 27 documents, reporting a total of 26 studies, which adjusted or controlled for age effects in their analyses of the relationship between pubertal status and self-regulation. However, the picture formed by synthesizing these studies is difficult to interpret. The studies reviewed here employed a limited set of the currently available instruments to assess hot and cool self-regulation, covering an equally limited set of constructs and abilities related to self-regulation. There was also considerable heterogeneity among studies in terms of the self-regulation constructs/measures under investigation and the tests/questionnaires that were used. Even studies that claimed to assess the same construct often used different instruments or different scores that were difficult to compare. This created considerable interpretation difficulties, especially when comparing studies with conflicting results because it could not be clearly established whether these results truly disagreed or merely reflected the use of different types of self-regulation. The heterogeneity in this literature was further increased by the use of varied pubertal indicators that are not directly comparable, either because of the lack of a clear match among different physical changes that index pubertal development, or due to a lack of a match between these physical markers and sex hormone concentrations (Dorn and Biro, 2011; França et al., 2022; Mendle, 2014; Mendle et al., 2019).

The reported results included a mix of non-significant and significant findings. This, in itself, would be natural given that statistical power often varies among studies, especially because the reviewed literature typically used a relatively small sample size and often made use of complex statistical models. More troubling is the presence of several results in opposite directions. Not only were there studies associating pubertal status (independently from age) with both increases and decreases in broadly-defined self-regulation; in many cases, significant results were often inconsistent and, at times, also in direct opposition, even when studies claimed to assess the same constructs, and used similar instruments.

Overall, there were few clear patterns in the distribution of positive, negative, and null result among studies when considering the general type of the abilities assessed (e.g., hot vs. cool self-regulation), regardless of whether hot self-regulation measured in the laboratory involved risks or sure wins, the instruments used (tasks vs. questionnaires) or the particular construct assessed (e.g., inhibition, working memory, impulsivity, etc.).

Comparison of results with predictions of cognitive developmental models

With a patchy coverage of self-regulation abilities and high heterogeneity in measures, scales, and analyses, a lack of clear patterns should be no surprise. This general inconsistency was observed for performance in measures that assess decision-making under risk/uncertainty and sure wins, generally regarded as hot skills, as well as for (cool) visuospatial working memory. Despite this, there were two mostly consistent sets of results inspiring some tentative conclusions considering the most cited models of cognitive development during adolescence. The first is the almost complete lack of reported effects in studies involving questionnaires of cool self-regulation in real-life scenarios (Chaku and Hoyt, 2019; Graber et al., 2006; except for a very small effect in females only: Ellis, 2002) and laboratory tasks that involve self-regulation abilities like access to long-term memory (verbal fluency: Herlitz et al., 2013/ Lovén, 2012; Waber et al., 1985), working memory updating, sustained attention (Sullivan et al., 2016) and, more markedly, inhibition, which was tested in many studies, albeit mostly using different tasks (Deater-Deckard et al., 2019; Gorday and Meyer, 2018; Mathias et al., 2016; Ordaz et al., 2018; Waber et al., 1985; with the exception of a small female-specific effect in Castagna and Crawley, 2021). The exception to this general lack of cool self-regulation effects occurred for visuospatial working memory tasks, which showed mixed results [improvement with sexual maturation in males only in two datasets (Davison and Susman, 2001; Herlitz et al., 2013/Lovén 2012), but two other studies found no consistent pubertal effects (Sullivan et al., 2016; Waber et al. (1985)]. In this case it is possible that results were confounded by the male advantage in these abilities that is observed from adolescence on (Voyer et al., 2017).

The second pattern in the results was the recurrent finding of negative pubertal effects on day-to-day hot self-regulation skills assessed with questionnaires, including failures in self-control (Chaku and Hoyt, 2019; Ng-Night et al., 2016), impulse control (Ellis, 2002; Warren and Brooks-Gunn, 1989) and emotional regulation (Koch et al., 2020/Mendle et al., 2020).

Together, these two apparent patterns (lack of pubertal effect on cool self-regulation abilities and negative pubertal effect on hot self-regulation in real life settings), seem in line with prevailing and popular imbalance models of cognitive development across adolescence, which propose that only hot abilities are associated with puberty (Shulman et al., 2016). Regarding cool self-regulation, the imbalance models posit that there is a gradual/linear pubertal-independent (Ernst et al., 2006; Shulman et al., 2016) improvement throughout adolescence due to the protracted development of the prefrontal cortex (for reviews, see Casey, 2015; Ernst, 2014; Ernst et al., 2006; Shulman et al., 2016). Thus, when age is corrected for, no pubertally-associated change in cool self-regulation should be found, as observed in general here.

The picture changes, however, when considering the prediction of the imbalance models in terms of the findings for hot self-regulation effects. These models propose that the system/module that involves mainly striatal (approach-/reward-driven) and amygdala (triadic model only) regions develop following a non-linear trajectory, dependent on pubertal status, with a maximum reward sensitivity and/or increased impulsiveness under conditions involving social or emotional responses (Casey, 2015; Ernst, 2014; Shulman et al.,2016) that reach an apex in the mid-teen years (Ernst, 2014; Shulman et al., 2016), which coincide with the end of puberty for most individuals (Marceau et al., 2011). At first glance, this seems compatible not only with findings of an increase in self-regulation failures assessed with questionnaires that assess hot self-regulation in real-life (Chaku and Hoyt, 2019; Ellis, 2002; Koch et al. 2020/Mendle et al., 2020; Ng-Night et al., 2016; Warren and Brooks-Gunn, 1989), but also with the findings of five studies that showed higher pubertal-related choice impulsivity in tasks that assess hot decision-making involving rewards (Kretch and Harden, 2014; Mathias et al., 2016; Cardoos et al., 2017; Laube et al., 2017, 2020). However, this apparent agreement between the reviewed data and the pubertal effects on hot self-regulation does not hold under further scrutiny for various reasons. First, given that the reports, using questionnaires, about daily life failures in hot self-regulation were in agreement only regarding early puberty, and exclusively in females, it may very well be that they do not relate specifically to self-regulation. This could be due, for instance, to difficulties in dealing with the beginning of mood fluctuation following the first menstrual cycles, a symptom that can affect up to 80% of females (Itriyeva, 2022). Second, the lack of pubertal effects on negative urgency (Mendle et al., 2020), loss-of-control eating (Vannucci et al., 2014) and social cognition difficulties (Vetter et al., 2013) do not square well with the models' predictions. Third, most results coincided regarding worse hot self-regulation in real life in early puberty, which usually *precedes* mid-adolescence, contrary to the models' predictions in terms of timing. There were also many inconsistencies among studies in aspects relevant to the dual systems models. For example, some studies reported nonlinear trends (Warren and Brooks-Gunn, 1989), others reported impairments throughout the whole of the puberty transition (Koch et al. 2020/Mendle et al., 2020), some only in early puberty (Chaku and Hoyt, 2019; Ng-Night et al., 2016) or reported no effects at all (Mendle et al., 2020; Vannucci et al., 2014; Vetter et al., 2013). Fourth, differently from the negative pubertal effects found in the five studies relating to hot decision-making in laboratory measures described above (Cardoos et al., 2017; Kretch and Harden, 2014; Laube et al., 2017, 2020; Mathias et al., 2016), two studies showed the opposite effect (Steinberg et al., 2008; Icenogle et al., 2019) and three studies showed no effects of pubertal status (Olson et al., 2009; Sullivan et al., 2016; Lee and Rasmussen, 2022).

Furthermore, we still failed to see a pattern regarding hot skills when we analyzed results considering whether laboratory measures involved risks/uncertainty or safe options with sure wins, which are purportedly differently affected across adolescence (Dafoe et al., 2015; Romer et al., 2017), with being more 'impulsive' supposed to be more prevalent under uncertainty, whereas as they develop, adolescents are believed to make better and better choices when sure win options are involved; however, we could not confirm this. A higher risk-taking profile (in tasks such as the Iowa Gambling Task, the Airport Auction Task, and simulated driving in the Stoplight Game) following pubertal status was found in two of four studies (Kretch and Harden, 2014; Cardoos et al., 2017), the other two of which found that responses became *less* risky as adolescents became more sexually mature (Steinberg et al., 2008; Icenogle et al., 2019). Regarding choosing between sure win options, three studies reported higher pubertal status-related preference for immediate rewards in delay discounting tasks (Laube et al., 2017, 2020; Mathias et al., 2016), but three other studies using the same type of paradigm found no effect (Olson et al., 2009; Sullivan et al., 2016; Lee and Rasmussen, 2022).

Moreover, a different reading of the predictions of the imbalance models is that hyperresponsive affective systems could lead adolescents to be more willing to wait longer for larger real rewards rather than preferring to gain less at shorter intervals (Scheres et al., 2014; see also Dafoe et al., 2015). It is also noteworthy that only one of the six studies that used delay discounting tasks actually had adolescents wait to gain rewards (Mathias et al., 2016), which can be aversive and lead to a preference for immediate choices. The other five studies seem to have been entirely hypothetical, asking participants to imagine how long would they would be willing to wait to gain virtual rewards. It is thus difficult to ascertain that these delay discounting tasks were really measuring heightened sensitivity to *real* rewards or aversion to having to really waiting for them. Regrettably, other types of choice/risk-taking paradigms (reviewed by Dafoe et al., 2015) were not tested in the selected studies in our review so we could not elaborate further on this matter.

Our results also failed to be informative regarding the predictions of another theoretical perspective on behavioral self-regulation in adolescence, namely social engagement shifts across this period of life (e.g., Nelson et al., 2016). Only two reviewed studies investigated the effects of social manipulation/social cognition [Kretch and Harden (2014) (taking risks when watched by peers) and Vetter et al. (2013) (theory of mind)], neither of which found pubertal effects interfered with results. As a whole, the reviewed studies did not confirm any predictions of developmental models except that cool self-regulation does not seem to be associated with pubertal status.

Critical evaluation of methodological issues in the literature

In addition to the interpretation issues raised so far, there are also an additional set of methodological questions that undermine our confidence on the internal and external validity of the findings reviewed here. One of the goals of this review was to critically evaluate the literature to understand how the characteristics of the studies affect the conclusions that can be draw from them. As discussed in the Methods section (see subsection “Criteria for study evaluation”), we focused our analysis on a set of aspects we judged as being critical for digging deeper into the interpretation of the results of the reviewed studies. These include the study design, the characteristics of the participants, the instruments used to assess self-regulation abilities and pubertal status, and the different aspects of the adequacy of the statistical analyses employed. In what follows, we discuss this analysis and its implications. We argue that the combined impact of all these issues is that, given the characteristics of the studies that have been carried out so far, it is as yet impossible to draw firm conclusions about whether and to what extent the general construct of self-regulation changes across pubertal maturation *per se*, independently of possible self-regulation changes that are expected to occur as adolescents grow older and gain experience.

Study design

One aspect in common to all of the reviewed studies is that they were observational studies – which, given our research question, is the only type of study possible. Moreover, the majority of the studies reviewed here were cross-sectional investigations involving participants of different ages, or longitudinal studies with participants of different ages at baseline. Because of this, and despite the complexities of the literature reviewed here, the lack of large, reliable and significant effects of pubertal status is hardly surprising; this is the other side of the age effects problem. We mentioned before that results that do not adjust for age effects are uninterpretable in terms of our research question. However, because of the strong correlation between age and pubertal status, the required statistical adjustments for participants' age can artificially reduce pubertal effects. After all, the shared variance of pubertal and age effects of the cognitive outcome is likely to be removed from the final effect when this type of statistical adjustment is used. Therefore, this approach does not fully disentangle these effects in observational studies.

In this scenario, the ideal solution would be to conduct longitudinal studies where participants are evaluated at the same ages, allowing the control of the effects of age without artificially reducing putative pubertal effects, so that, in theory, it would be possible to investigate to what extent pubertal development, as opposed to experience, learning, and non-pubertally induced physiological brain changes mediate/moderate the effects of age on cognitive/behavioral measures. Only one study in our sample, Chaku and Hoyt (2019), employed such a design. This study included around 1,000 adolescents and assessed Tanner stages and parent-reported questionnaires of attention and self-regulation yearly over a seven-year period. However, data on self-regulation and attention were not collected in several study waves, including those encompassing the ages when most of pubertal development takes place. This significantly limited how informative this study could be to our review question and may partly explain the lack of longitudinal pubertal effects.

Sample characteristics and external validity

While we noted the heterogeneity of the studies included in this review, they were not heterogeneous in all aspects. Sample demographics were mostly similar among the majority of the reviewed studies. Overall (although with exceptions), the samples studied in this literature conformed to the general pattern that has been nicknamed W.E.I.R.D, meaning that participants were from western, educated, industrialized, rich and democratic societies (Henrich et al., 2010). There is no denying that the countries represented in this literature are far from homogeneous. The USA, the most represented country in this literature, has individuals of different ethnicities and from widely variable SES backgrounds, as can be seen in their most recent census (see https://www.census.gov/newsroom/press-releases/2022/acs-5-year-estimates.html and links therein). However, not even this within-country diversity was fully represented in the samples. Based on reported demographic data – that is, from studies that actually reported such data – participants were mostly White and from middle- to upper-class families.

There have been calls for increasing diversity in the study of adolescent development because it is known that several factors related to ethnic, culture, and SES can influence different aspects of adolescents physiological and psychological development (Blum and Boyden, 2018; Hertliz et al., 2013; McLean and Riggs, 2021; Mendle et al., 2019; Steinberg et al., 2017; Worthman et al., 2019). We should note, however, that this issue is not exclusive of the literature reviewed here, as psychologists of different sub-disciplines have become aware in recent years (Amir and McAuliffe, 2020; Fernández and Abe, 2017; Hartmann et al., 2013; Henrich et al., 2010, and associated commentaries). The lack of diversity in study participants is a widespread problem whose significance is still to be fully determined. One thing is for sure, this lack of diversity threatens studies' external validity. We simply cannot know how generalizable most of the reported results are, so interpreting them as results pertaining to "adolescents in general" creates a risk of bias.

Issues with cognitive/behavioral measures

As we noted in the Results section, there was a great variability among studies in the instruments employed to evaluate self-regulation and related capacities. The literature is full of terminological disputes and divergent theoretical frameworks that can influence the choice of measures, leading to the identified variability. This results in different tasks and questionnaires, which measure different aspects of cognition, being used to assess the same constructs. In addition, even among instruments that actually measure the same construct, it is common to find different task scores and/or considerable task impurity that, along with other factors, leads to measurement error and limits construct and convergent validity. It is unlikely that reliable conclusions can be draw by directly comparing the results of, say, a study using the attention sub-scale of the CBCL with the results of another study that tested attention using the Continuous Performance Test. While both measures may assess the same general domain underlying construct – "attention" – each task/questionnaire also captures other abilities, and these differ from one instrument to the other. This is a serious issue because elevated measurement error threatens the validity of study results in different ways, depending on the characteristics of the data and analyses (Carlson and Herdman, 2010; Loken and Gelman, 2017; Westfall and Yarkoni, 2016). Of note, these issues are neither new in the study of self-regulation (e.g., Duckworth and Kern, 2011; Fernández-Marcos et al., 2017) or unique to this field (Flake and Fried, 2020; Meyer et al., 2001).

One strategy to deal with measurement error and convergent/construct validity issues is the use of latent variable approaches under structural equation models (e.g., Friedman & Miyake, 2017; Karr et al., 2018; Royall et al., 2002; Westfall and Yarkoni, 2016). This method uses multiple tasks that are believed to measure the same construct and their shared variance (latent trait) is used as a dependent variable. The variance in performance that is unique to each variable is partialed out so that these latent variables are likely less impure and also free of measurement error. However, the few selected studies that used more than one self-regulation measure aimed to assess distinct self-regulation abilities with each measure, so latent traits could not be determined.

Issues with pubertal measures

The PDS was the most commonly used method to assess pubertal status in the studies reviewed here. The reasons for this prevalence are easy to guess. The PDS is often self-rated, can be completed in any setting, does not involve having to undress or answer questions about changes in genitalia, both of which can be embarrassing for some youngsters; it is also an open access, more affordable measure, easier to complete and score than other instruments, such as physical examination (Tanner method) or hormonal analyses. However, the PDS also has significant limitations, including the fact that it does not measure pubertal status *per se* – rather, it measures "perceived pubertal status" (Cheng et al., 2021). Accordingly, there are systematic discrepancies between PDS ratings and ratings from physical examination by clinicians, with less developed adolescents overestimating their development and more developed adolescents underestimating theirs (e.g., Shirtcliff et al., 2009).

In turn, Tanner staging based on physical examination by an experienced physician or nurse is regarded as the gold standard for assessing pubertal status (Dorn and Biro, 2011; Dorn et al., 2006; Mendle et al., 2019; Walker et al., 2019) because it is believed to be more objective and reliable than self-reported measures; however, it also has some limitations. Tanner stages are based on a limited set of physical characteristics and are based on norms established several decades ago on a sample with limited diversity. Furthermore, it is not clear how objective and reliable this method is, as there can be substantial inter-rater variability (Dorn and Biro, 2011; Dorn et al., 2006). Moreover, while Tanner stages are based on definite characteristics, it is possible – and we would say even probable – that clinicians' rating of particular characteristics is influenced by all developmental signs that are perceptible during physical examination, not just those included in the Tanner method, as pointed out long ago by Morris and Udry (1980). Also, it requires having a clinician or trained nurse to do the evaluations, which substantially increases study costs. In sum, both the PDS and Tanner stages have advantages and disadvantages and are comparable in terms of being indirect measures of puberty's unfolding (França et al., 2022). Because of this, the level of information they can deliver is limited by different factors, such as self-report bias, observer error, and contextual confounders (Worthman et al., 2019).

Limitations also apply to measurement of hormone levels, even though this is supposed to be a more "direct" and objective measure of pubertal developmental status because they reflect the immediate products of the neuroendocrine events that compose puberty. This seems especially true if it is considered that the effects of pubertal status on cognitive abilities are caused by hormonal actions in the brain. Hormonal measures are thus proposed by some to be more informative than physical measures. While there are strong correlations between hormones and physical measures of puberty (*r* values ranging from .6 to .7 in Shirtcliff et al. [2009]) there is still a significant amount of variation in hormone concentrations that is not captured by the physical measures. In fact, pubertal hormonal levels cannot be clearly matched to stages of physical development (Dorn and Biro, 2011; Dorn et al., 2006). However, this divergence between physical measures and hormone levels may have multiple causes. The determinants of hormonal effects include many other factors in addition to their circulating levels. These include the concentrations of hormone-binding proteins, and the distribution, density, and particular isoform/genetic variant of hormone receptors in the different target tissues (Dorn et al., 2006; Ponzi et al., 2020). Some of these factors can vary both between individuals as well as within individuals over time – and with them the effects of hormone exposure (Auyeung et al., 2013; Ponzi et al, 2020; Schulz et al., 2009). These factors may contribute to the less-than-perfect correlations between hormones and PDS or Tanner, and to variations in the synchronicity of different aspects of physical changes during puberty. Importantly, these factors may also lead to significant individual variability in the association between hormonal levels and brain development.

Despite their limitations, the fact is that PDS, Tanner staging, and hormonal measures are among the best measures of pubertal status we have right now. But they measure different things, and thus provide different information. Much like the notion of "development" itself, puberty is a concept we use to designate a complex set of interrelated processes, and can only be observed indirectly through these measures, so may be best characterized by the shared variance (latent variable) of many pubertal measures, because our current individual instruments offer a rather noisy picture of this construct. Because we cannot know all the factors that determine the effects of pubertal hormones on the brains of each individual, and because the effects of pubertal hormones vary from tissue to tissue, an estimation of pubertal status based on multiple indicators is probably the most reliable and robust measure we can obtain. Latent pubertal measures could even be improved over time by adding more measures as new methods and biomarkers are developed. The incorporation of latent constructs in studies involving puberty has been called for before (Dorn and Biro, 2011) and we have seen recent steps in this direction (Byrne et al., 2019; Herting et al., 2021), although there is still a long way to go before this strategy becomes widespread. We discuss this issue further in França et al. (2022). Hence, future studies should strive to obtain multiple measures of puberty and associate the effects of a latent variable obtained from them with self-regulation abilities.

Statistical issues

Statistics is involved in most of the issues already discussed above. It is relevant to the problems of measure (un)reliability, and also plays a key role in the solution of this problem. Furthermore, the whole issue surrounding the confounding effects of age is essentially a statistical one. However, there are two additional statistical difficulties we have not yet discussed. The first one is the significant variability in the reporting of statistical results and in the characteristics of statistical models employed; the second pertains to linearity – or lack thereof.

A significant source of difficulty when interpreting and comparing results was the variation in the statistical approaches used in each study, including significant diversity in the number and identity of control variables included in the statistical models. Besides adjusting their analysis for age, which was a requirement for inclusion in the review, most studies adjusted their analyses for some known confounders together with the variables of interest to each study. Variables added to statistical models included sex, SES, ethnicity, school grade, intelligence, among others. However, no study adjusted for all those variables, some adjusted for no variables other than age, and others included covariates in their models that were of no interest to our review whatsoever.

There was also great variability in the precise statistics reported in each study (e.g., correlation or partial correlation coefficients, coefficients of determination, standardized or unstandardized regression coefficients, all of which mostly lacking in, or varying in the reported confidence intervals). Also, when significant associations were found, they were mostly of small magnitude (although there were exceptions). This makes it difficult to evaluate, let alone compare, the magnitude and precision of effects from different studies.

As for the second issue, most of the statistical models used in the reviewed studies were linear models – as is standard for most experimental fields in psychology and biology. However, these models may not be the best ones for dealing with biopsychological development during adolescence. Most of the developmental processes during this period are nonlinear: pubertal development is not linear (e.g., Marceau et al., 2011), brain development during adolescence is not linear (e.g., Foulkes and Blakemore, 2018; Gracia-Tabuenca et al., 2021), behavioral changes during adolescence are not linear (e.g., Steinberg et al., 2016). In fact, when the subject is adolescent development, it seems that nothing is linear except our models.

The issue of non-linearity, however, may be more serious when studying adolescents from a wider age range. For studies that involve participants of a limited age range, linear models may be a good approximation of the developmental effects/trajectories. Nonetheless, to fully understand the developmental processes occurring during adolescence, statistical models that better capture the pubertal transition as a whole are needed. Accordingly, there have been calls for the development of nonlinear approaches in the literature, and nonlinear models are starting to be explored with promising results, but here too much still remains to be done (Susman et al., 2019; Worthman et al., 2019).

Summary and going forward

When talking about future directions, we find ourselves in a situation that resembles the serenity prayer - There are difficulties we can resolve, and there are those we cannot - we must accept the former and try to solve the latter, but first we must know the difference. Thus, faced with the challenges of disentangling the cognitive and behavioral effects of pubertal status from other developmental factors that are not puberty-related and that change as adolescents age (e.g., learning/gaining experience), the first question we may ask is, can we really do it? Apart from information that can be gathered from clinical cases of individuals with (neuro)endocrine pathologies, our main tool for investigating the effects of pubertal status on self-regulation and associated abilities in humans are observational studies. However, the deep interactions between the effects of growing older and going through puberty on the development of cognitive skills make it very difficult to disentangle their effects.

Some effects of pubertal status may well be non-separable from those of experience at the level of behavior. For example, there is evidence that increases in estrogen concentrations during puberty can change the inhibitory tone in the frontal cortex of mice (Piekarski et al., 2017). Such changes would not only affect the neural representations in this region, but could also affect neuronal plasticity. In fact, increases in the activity of inhibitory interneurons are linked to the opening of sensitive periods in other brain regions at different stages of development (Hensch, 2005; Takesian and Hensch, 2013). Thus, this effect of estrogen may not only lead to an “immediate” change in behavior (by changing the dynamics of neural representations), but also change the effects of experience over time through its effects on plasticity. This latter effect would involve an interplay between a pubertal effect and learning from experience. There is also evidence that sex hormones influence various aspects of behavior, including mood and social cognition (Auyeung et al., 2013; Schulz and Sisk, 2016; Schulz et al., 2009). This can influence how adolescents perceive different stimuli/situations (Nelson et al., 2014, 2016) and how others perceive and react to adolescents (Arnett, 2008), thus influencing the process through which individuals build their environments over time, which then feeds back to influence subsequent development (Scarr and McCartney, 1983).

As discussed by Ernst (2014), adolescence is a time in which a complex balance between transient and trait factors lead to large inter-individual differences in behavior, which may make it even harder to find a pattern of responses considering pubertal effects, especially when using small samples, as was the case of most reviewed studies. Transient factors include not only physical states such as pubertal status, but also mental states and mood, context (home, school, or non-social environments such as the laboratory), progressive re-attribution of social values (Ernst, 2014), as well as the opportunities to take risks in real life, the levels of risks involved in decision-making and the size of possible rewards (Dafoe et al., 2015; Romer et al., 2017), all of which can interact in different ways. These changes are also influenced by trait factors such as genetics, personality, and past experiences (Ernst, 2014).

Taken together, we believe these issues will require statistical models that are more informed by theory (a need already highlighted in the literature [e.g., Susman et al., 2019]). Developing the theoretical insights to inform these models, however, will be a challenge on its own. Currently, the most popular models involving the development of self-regulation during adolescence are varied dual systems and the triadic models [reviewed by Casey (2015), Ernst (2014), Ernst et al. (2006), Shulman et al. (2016)]. Less cited models highlight the effects of learning by accumulation of experience in decision-making, which differs throughout adolescence depending on a host of factors such as risk probabilities [reviewed by Dafoe et al. (2015 and Romer et al. (2017)]. While these models have many conceptual similarities, they vary in their emphasis on the role of different brain regions or networks, of learning by experience and in their precise behavioral predictions, including their proposed trajectories of behavioral change. As discussed above, while the results of lack of pubertal effects on cool self-regulation performance and the worsening of hot self-regulation pertaining to daily life in early-adolescent females reviewed here were partly consistent with the general tenets of the imbalance models, despite the latter having been mostly accordant not in mid- but in early puberty, other tasks and questionnaires that assess self-regulation that should have been affected according to these conceptual models did not show clear results. We also failed to find consistent effects regarding decision-making performance under risks and sure wins, resulting in a lack of evidence supporting models that underscore these variables as essential to describe adolescent behavior. Therefore, the literature reviewed here does not provide strong support for any of these models. In fact, evidence for the imbalance models – and specially to disambiguate between them – has been hard to come by as there are some important theoretical and methodological difficulties in testing them that have not been appropriately met (Meisel et al., 2019; Pfeifer and Allen, 2012, 2016).

Currently, the triadic model (Ernst, 2014; Ernst et al., 2006) seems to be more comprehensive in explaining pubertal effects because it also accounts for avoidance behavior in aversive situations by considering, in addition to the two systems of dual-systems models, a third, emotion-related neural system that involves the amygdala, hippocampus, and insula. Higher behavioral difficulties associated with puberty regarding emotional response intensity and liability (possibly including social salience) could thus possibly relate to this third module. Teasing these models apart will require studies using sets of tasks that are sensitive to differences in frontal, striatal, and amygdala networks and that take social aspects and risk probability versus choosing between sure win options into account, preferably in the same individuals, with longitudinal designs, large samples and a host of other factors discussed above.

Further development and refinement of rigorous and testable theories and models will require the integration of all the evidence available. This means combining insights from both human and animal studies, as the latter allow for the investigation of plausible mechanisms and how they may limit possible detectable effects at the behavioral level, helping to set realistic expectations for the results of future studies. We will also need to integrate information from investigations of pubertal processes involving different physiological systems and at different levels of organization, from the molecular to the behavioral level. In other words, we will need all the information we can get to appropriately constrain our models and provide a context for the interpretation of future results (Susman et al., 2019).

Considering all the issues raised in this review so far, we believe that, if we are to have a chance of disentangling the effects of pubertal status on the development of self-regulation and related capacities, we will need: 1) more longitudinal studies; 2) studies with more diverse samples; 3) studies using multiple measures of pubertal development and self-regulation, with adequate statistical methods to deal with measurement error in individual instruments (e.g., latent variables); and 4) more studies with nonlinear, theory-informed models. Of note, points 2, 3, and 4 are actually more urgent than point 1, because there is no use in conducting large longitudinal studies when there are still uncertainties about what to measure and how to do so.

Additionally, we should invest in the creation of public databases to allow full use to be made of the available data. Pubertal data can be analyzed in multiple ways, and thus the same data can be used to answer very different questions, as the diversity of questions investigated with data from the large ABCD study illustrates (Cheng et al., 2021). In fact, the data from most studies listed in the **Table S1**, as well as data from studies with relevant measures but that did not report results for the associations between pubertal status and cognitive/behavioral outcomes of interest, could be used, at least in theory, to help answer our review question. Making data publicly available would allow the scientific community to make the most out of data – a moral imperative, given that most scientific studies receive public funding.

Finally, this move towards open datasets should be following by a general move towards greater transparency in research reports. In fact, the most common methodological issues found in the studies reviewed here were related to transparency, such as the incomplete reporting of the demographic characteristics of participants. Often, there was insufficient information about cognitive and pubertal measures and statistical analyses and results, which created difficulties for interpreting the findings, and would certainly create difficulties for replicating the studies. Additionally, registered protocols were only available for Vannucci et al. (2014), and only one of the studies (Chaku and Hoyt, 2019) included information on data availability.

The problem of transparency is particularly important when talking about measures such as tasks and questionnaires. For example, more often than not, full questionnaires are not made available with the research reports, with papers describing only a few sample items from the questionnaire. The full questionnaires can be proprietary tools, inaccessible to researchers with low resources, or be hidden behind a never-ending trail of references, where one paper cites another as the source, which in turn cites another, and so on, with the original full questionnaire being difficult or even impossible to locate. This issue is not particular to this literature, and greater use of open-access pubertal and self-regulation measures and transparency would go a long way in allowing the development of a more inclusive and democratic field of research, as well as a deeper appreciation of the data that has accumulated over decades about cognition in adolescence.

Review limitations

Disagreements about the definition of self-regulation and related concepts – which are rife in the literature – could have led to different criteria for including tasks and questionnaires in this review, as well as in the way we categorized them into hot and cool measures and so forth. In addition, our search for gray literature could have involved additional methods, like searching Google Scholar (Haddaway et al., 2015) or thesis/dissertation repositories. We also did not attempt to obtain original datasets from all of the studies whose data could possibly be reanalyzed for the purposes of our review question – which would require not only obtaining the data in question, but also developing appropriate models for performing the analyses, which is beyond the scope of the present work. We note, however, that the limitations identified in the literature reviewed here are widespread, and they significantly, and often fundamentally, limit how informative available data can be in respect of our review question. Therefore, we do not believe any of the limitations above would significantly change the main conclusions of this review. An additional limitation was our focus on typically-developing adolescents. Clinical groups may show different patterns of relationship between pubertal development and self-regulation abilities.

Conclusion

Our review revealed significant heterogeneity in the methods and results of the available studies about the relationship between pubertal development and self-regulation. There were only a few seemingly consistent findings, and these of questionable significance: a lack of pubertal effects on cool cognitive abilities when age is adjusted for, although very few studies used the same cognitive measures. The convergence of several methodological maladies widespread in the psychological literature, combined with the inherent difficulties in disentangling the effects of highly correlated variables (pubertal status and age) in observational studies, significantly limit how informative the available literature is for determining the effect of pubertal status on self-regulation. Although there is widespread conviction that pubertal status affects self-regulation and related abilities, there is limited direct evidence for this effect in humans. This is not to say that there is no evidence for the effects of pubertal status on self-regulation. Animal studies, for example, do suggest that pubertal development influences brain regions generally involved in self-regulation, although most of the cognitive abilities within this umbrella-term are inherently human. Nonetheless, the lack of studies, and especially longitudinal studies, with multiple measures of pubertal status and cognitive abilities related to self-regulation, and appropriately designed for the purpose of disentangling the effects of pubertal development from age effects, makes it very difficult to confirm the effects of pubertal status on self-regulation in humans at the level of behavior, and to assess the magnitude of such effects.

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Box 1 – Risk-taking, sensation seeking, and their relation to self-regulation

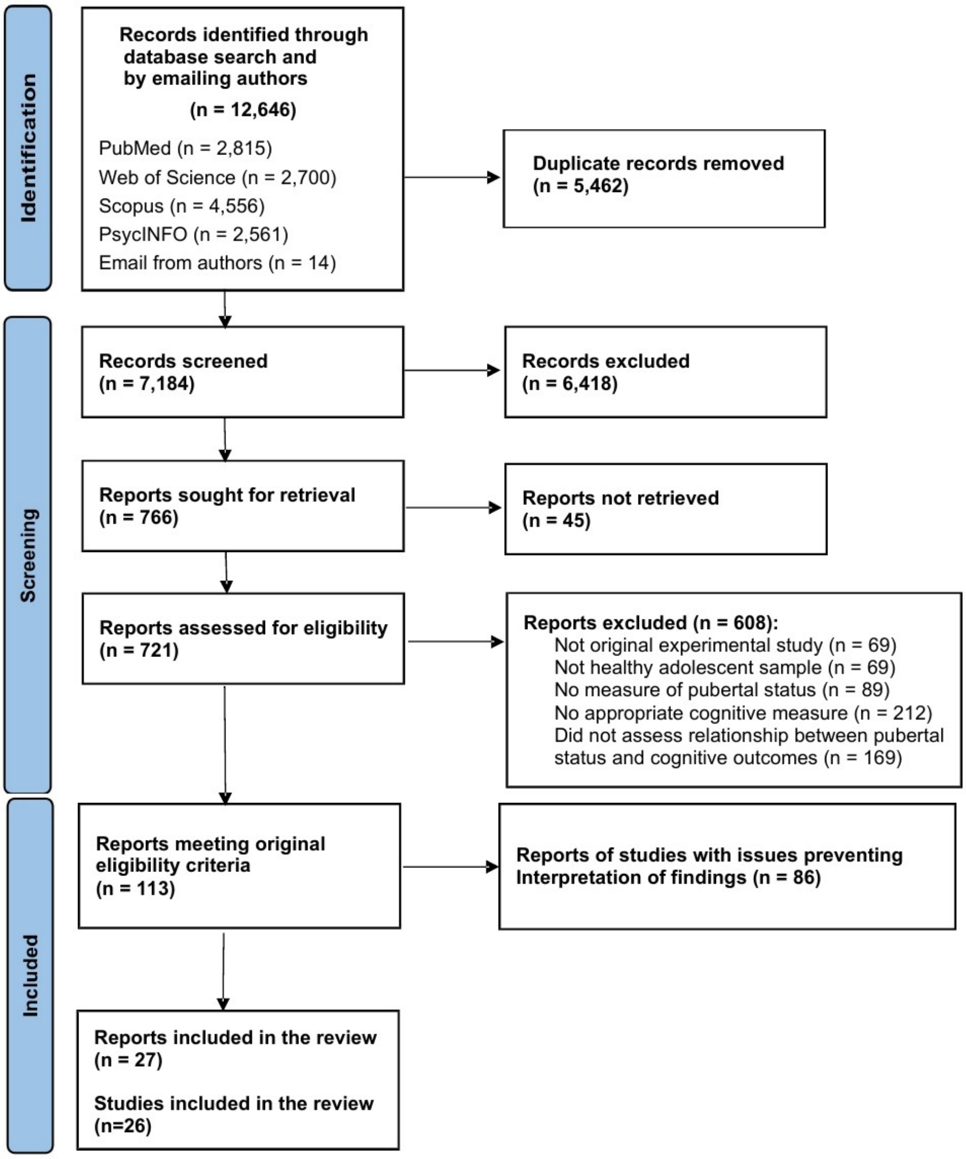
A notable absence in this review is that of studies employing many types of measures usually regarded as assessing risk-taking, sensation seeking, and related constructs such as reward sensitivity. While these constructs are usually associated with self-regulation (e.g., Robson et al., 2020; Ridder et al., 2012), the constructs themselves and the instruments used to measure them do not necessarily assess the capacity for self-regulation as defined in our study.

Let us start with risk-raking questionnaires. Many (though not all) behaviors commonly considered as risk-taking, such as alcohol and drug use, and sexual activity, should not be automatically regarded as failures of self-regulation. Adolescents may deliberately choose to engage in these activities and even go to great lengths to do so. Thus, the goals of the adolescents themselves in engaging in a behavior should be taken into account, not just its potential outcome (Do et al., 2020). Furthermore, to consider a behavior as a failure of self-regulation and a "risk-taking" behavior implies that the individual fully appreciates the risks involved (Jessor, 2018), which may not be the case because adolescents can lack knowledge and experience to do so. Also, it cannot be disregarded that at least part of the variability in "risky" behaviors reflect differences in risk-exposure – i.e., in the opportunity to take such risks – not in risk-taking (Defoe et al., 2015; Defoe et al., 2019), as the former tends to increase as adolescents grow older because of progressive reduction of parental supervision.

According to Romer et al. (2017), decision-making differs depending on risk probabilities. There are many different types of risk-taking, only some of which are maladaptive and may peak during adolescence. This phase of life is marked by behaviors associated with sensation seeking and impulsive action that are specifically motivated to allow the exploration of the environment. But these risky behaviors are only more prevalent in adolescents than in adults and children under conditions in which risk outcomes are uncertain or ambiguous; when the risks are unambiguous, that is, when the outcomes can be clearly calculated (e.g., both involve sure winds of different magnitudes), adolescent behavior is midway between that of children and adults, indicating that the self-regulation abilities involved in this type of decision-making develop linearly and do not peak in adolescence (Romer et al., 2017). Some individuals, however, do seem to be insensitive to risk. They present high levels of acting without thinking or difficulties with self-regulatory impulse control that precedes adolescence, increases in adolescents and remains elevated in adulthood (Romer et al., 2017). Therefore, risk-taking/impulsive action in adolescence has many possible interpretations that essentially depend on the type of choice that they must make. Determining failures of self-regulation in conditions involving risks and benefits should ideally be done considering whether choices involve actual risks, the probability of being exposed to decision-making that involves different probabilities and the ability of adolescents of appreciating these risks. Furthermore, questionnaires that address self-rated self-regulation *failures* in ecologically valid circumstances, that is, in real life, present a particular case of interest to determine how pubertal status affects behavior during adolescents' daily lives.

In tasks involving risk-taking, if the results are to be used as an index of self-regulation, the task must have a strategic component that requires the capacity to choose the best course of action – and the performance in the task must assess whether or not the test-taker succeed in doing so. To illustrate this point, consider the Balloon Analogue Risk-Taking task (BART; Lejuez et al., 2007), and its recent cousin, the Balloon Risk-Avoidance Task (BRAT; Crowley et al., 2021). Both these tasks can involve strategic decision-making under uncertainty, where participants gain points by progressively inflating or deflating virtual balloons through button presses, but lose all points if the balloon burst, which occurs at unexpected levels of balloon total size. The ideal performance must reflect a balance between inflating the balloon as much as possible (in the BART) or deflating it as little as possible (in the BRAT) while avoiding explosions, so that "risk-takers" or "impulsive" individuals should end up with less points than people who are more cautious/less impulsive. However, many studies on adolescents (e.g., Crowley et al., 2021; Collado et al., 2014; Loman et al., 2014) do not take into account the number of balloons that burst or the participants' final earnings. Instead, they used scores like the total number of balloon pumps independently of whether that balloon burst, which does not reflect how participants fare when trying to balance earning more points with the possibility of bursting the balloons. Consequently, these performance variables do not index self-regulation or related capacities.

As for sensation seeking and reward sensitivity, instruments that assess these constructs often evaluate something that fits more into the category of personality traits or "tastes and preferences" than in the category of "self-regulation abilities". Examples include questions such as "I would like to learn to fly an airplane" from the widely used Zuckerman Sensation Seeking Scale-V (Zuckerman, 2014), or the item "I like new and exciting experiences, even if I have to break the rules" from the Brief Sensation Seeking Scale–4 (Stephenson et al., 2003). We and others (e.g., Romer et al., 2017) consider that people who actively search for sensations and rewards, and may employ their capacities towards attainment of these goals would not be regarded as having self-regulation difficulties. For these reasons, studies examining the effects of pubertal development on scores of tasks/questionnaires with the characteristics above were not included in this review.



Template from: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

Figure 1. Flow diagram with the results of the study selection process. Of note, reports that presented “issues preventing interpretation of the findings” includes studies that did not adjust for age effects, and/or adjusted for them in an insufficient or inadequate way, and/or used pubertal data to create variables that were not interpretable in terms of pubertal status, and/or studies that assessed pubertal status and self-regulation outcomes at different ages. Many studies failed in more than one of these categories. For further discussion of this issue, see the Introduction and Discussion sections.

Table 1 – Search strings used for each search engine

Search engine	Search string
PubMed	(("Puberty"[Mesh] OR “Puberty”[tiab] OR “Pubertal”[tiab]) AND ("Executive Function"[Mesh] OR "Self-Control"[Mesh] OR "Emotional Regulation"[Mesh] OR "Problem Solving"[Mesh] OR "Attention"[Mesh] OR "Inhibition, Psychological"[Mesh] OR "Intelligence"[Mesh] OR "Cognition"[Mesh] OR "Decision Making"[Mesh] OR "Theory of Mind"[Mesh] OR "Impulsive Behavior"[Mesh] OR "Emotional Intelligence"[Mesh] OR "Risk-Taking"[Mesh] OR "Facial Expression"[Mesh] OR "Facial Recognition"[Mesh] OR "Delay Discounting"[Mesh] OR "Reward"[Mesh] OR "Academic Success"[Mesh] OR “Self-regulation”[tiab] OR “self-control”[tiab] OR “behavioral control”[tiab] OR “behavioural control”[tiab] OR “behavioural regulation”[tiab] OR “behavioral regulation”[tiab] OR “regulation of behavio*”[tiab] OR “control of behavio*”[tiab] OR “executive function*”[tiab] OR “central executive”[tiab] OR “executive control”[tiab] OR “executive network”[tiab] OR “inhibitory control”[tiab] OR “cogniti*”[tiab] OR “Working memory”[tiab] OR “Intelligence”[tiab] OR “attention*”[tiab] OR “decision making”[tiab] OR “decision-making”[tiab] OR “academic achievement”[tiab] OR “academic success”[tiab] OR “emotion regulation”[tiab] OR “emotional regulation”[tiab] OR “emotion control”[tiab] OR “emotional control”[tiab] OR “regulation of emotion”[tiab] OR “control of emotion” OR “theory of mind”[tiab] OR “facial recognition”[tiab] OR “facial expression*”[tiab] OR “reward”[tiab] OR “sensation seeking”[tiab] OR “Risk taking”[tiab] OR “risk-taking”[tiab] OR “impulsiv*”[tiab] OR “impulse control”[tiab] OR “novelty seeking”[tiab] OR “novelty-seeking”[tiab] OR “delayed discounting”[tiab] OR “temporal discounting”[tiab]))
Web of Science	TS=((puberty OR pubertal) AND (“self-regulation” OR “self-control” OR “behavio* control” OR “behavio* regulation” OR “regulation of behavio*” OR “control of behavio*” OR “executive function*” OR “central executive” OR “executive control” OR “executive network” OR “inhibitory control” OR cogniti* OR “working memory” OR intelligence OR attention* OR “decision-making” OR “decision-making” OR “academic achievement” OR “academic success” OR “emotion* regulation” OR “emotion* control” OR “regulation of emotion” OR “control of emotion” OR “theory of mind” OR “facial recognition” OR “facial expression*” OR reward OR “sensation seeking” OR “risk taking” OR “risk-taking” OR impulsiv* OR “impulse control” OR “novelty seeking” OR “novelty-seeking” OR “delayed discounting” OR “temporal discounting”))
Scopus	TITLE-ABS-KEY((“puberty” OR “pubertal”) AND (“self-regulation” OR “self-control” OR “behavio* control” OR “behavio* regulation” OR “regulation of behavio*” OR “control of behavio*” OR “executive function*” OR “central executive” OR “executive control” OR “executive network”

	OR “inhibitory control” OR “cogniti*” OR “working memory” OR “Intelligence” OR “attention*” OR “decision-making” OR “decision-making” OR “academic achievement” OR “academic success” OR “emotion* regulation” OR “emotion* control” OR “regulation of emotion” OR “control of emotion” OR “theory of mind” OR “facial recognition” OR “facial expression*” OR “reward” OR “sensation seeking” OR “risk taking” OR “risk-taking” OR “impulsiv*” OR “impulse control” OR “novelty seeking” OR “novelty-seeking” OR “delayed discounting” OR “temporal discounting”))
PsycINFO	((puberty OR pubertal) AND (“self-regulation” OR “self-control” OR “behavio* control” OR “behavio* regulation” OR “regulation of behavio*” OR “control of behavio*” OR “executive function*” OR “central executive” OR “executive control” OR “executive network” OR “inhibitory control” OR cogniti* OR “working memory” OR intelligence OR attention* OR “decision-making” OR “decision-making” OR “academic achievement” OR “academic success” OR “emotion* regulation” OR “emotion* control” OR “regulation of emotion” OR “control of emotion” OR “theory of mind” OR “facial recognition” OR “facial expression*” OR reward OR “sensation seeking” OR “Risk taking” OR “risk-taking” OR impulsiv* OR “impulse control” OR “novelty seeking” OR “novelty-seeking” OR “delayed discounting” OR “temporal discounting”))

Table 2. Summary of the characteristics of the studies selected for the review and their findings regarding the effects of pubertal status on self-regulation after adjusting for age.

Study id	Study design	Sample size	Participant demographics	Pubertal measure(s)	Outcome measure(s) of interest	Method to adjust for age effects	Summary of findings
Cardoos et al., 2017	Cross sectional.	63	**Age**: mean(SD) = 12.74(1.09) years; range = 10-14 years. **Sex**: females only **Ethnicity**: 52.4% White; 22.2% Mixed race/ethnicity; 11.1% Black/African American; 7.9% Hispanic/Latino; 4.8% Asian; 1.6% Other **School grade**: not reported. **SES**: mean SES Community Ladder = 6.83 (0–10 scale) **Country/region of origin**: USA	**Pubertal Development Scale** (PDS; Petersen et al., 1988). **Salivary testosterone, estradiol and DHEA,** analyzed with enzyme immunoassay kits.	**Airport Auction Task** (van den Bos, 2008; 2013), adapted for the study.	Age was included as a covariate in the statistical models**.**	Both PDS and testosterone, but not estradiol and DHEA, had small-to-medium, positive effects (adjusted for age) on overbidding and negative effects on final earnings in the task.
Castagna and Crowley, 2021	Cross sectional.	103	**Age:** mean(SD) = 14.49(1.69) years. **Sex:** Both**.** 55 male, 48 female. **Ethnicity:** Caucasian (n = 79, 76.7%), African American (n = 9, 8.7%), Hispanic (n = 6, 5.8%), Asian (n = 6, 5.8%), other/unknown (n=3, 2.9%). **School grade:** not reported. **SES:** not reported.	**Pubertal Development Scale** (PDS; Petersen et al., 1988).	**Flanker task.**	Age was included as a covariate in the statistical models**.**	Analyzing the parameters of two different decision models fitted to the task data, there was a small effect of the interaction between sex and PDS (adjusted for age), with a negative effect of PDS for females but not males on a parameter representing the amount of information that is considered for a decision. No other effects were found.

Chaku and Hoyt, 2019	Longitudinal.	1099	**Age:** 9.5 years at baseline, 15.5 at last measurement. **Sex:** both. 51% female **Ethnicity:** 81.4% White, 11% Black and 7% of another race/ethnicity (black and other were collapsed in a single category). **School grade:** not reported**.** **SES:** youth had mothers with 14 years of education on average (i.e., some college), the average income-to-needs ratio was 4.37 (SD = 3.14), and 85% of sample lived in a two-parent household (all SES variables assessed at age 9.5 only). **Country/region of origin:** USA**.**	**Tanner staging criteria (T**anner, 1962), assessed by experienced physician.	**Attention subscale of the Child Behavior Checklist** (CBCL; Achenbach and Edelbrock, 1991), reported by the participants' mothers. **Self-control subscale of the Social Skills Rating System** (SSRS; Gresham and Elliot 1990), reported by the participants' mothers. Note: both outcomes were assessed at ages 9.5, 10.5, 11.5 and 15.5.	Study used linear growth curve modeling to compute an intercept and slope from the time series of Tanner stages measured at the same ages (year and month) for all individuals.	Found a small, negative effect of pubertal status (adjusted for age) at baseline and social skills at baseline for girls. The effect remained when comparing data for the second wave instead of baseline. No other significant effects were found.
Davison and Susman, 2001	Longitudinal.	108	**Age (at baseline)**: for males: mean(SD) = 12.7(1.32) years, range = 10 to 14 years; for females, mean(SD) = 11.99(1.55) years, range = 9 to 14 years. **Sex**: both. 56 males and 52 females. **Ethnicity**: 97% Caucasian, 3% African-American **School grade**: not reported. **SES**: participants were predominantly middle and upper-middle class. **Country/region of origin:** USA.	**Blood levels of testosterone and estradiol**, measured using radioimmunoassay. **Tanner stages** (Marshall & Tanner, 1969,1970; Tanner, 1962), assessed by nurse practitioners.	**The spatial relations subscale of the Primary Mental Abilities test** (PMA; Thurstone, 1962). **Block design subscale of the Wechsler Intelligence Scale for Children–Revised** (WISC-R; Wechsler, 1974).	Adjusted for age by adding it as a covariate in the regression analyses. However, age was not adjusted for in all relevant analyses.	There were positive, medium-to-large effects of testosterone (age adjusted) on block design and mental rotation scores for boys for data from waves 1 and 2. There was also a positive effect of estradiol on block design for data from wave 2 for males. Longitudinal analyses also found associations between linear trend scores for mental rotation and testosterone for males. For females, there was an effect of testosterone on mental rotation at wave 3. No other effects were found in the analyses that adjusted for age effects.
Deater-Deckard et	Cross sectional.	157	**Age: mean(SD) =** 14.07(0.54) years; range = 13–	**Pubertal Development Scale**	**Multisource-interference task**	Age was included as a covariate in the	No effects of PDS scores on task

al., 2019			15 years. **Sex: both.** 52% male **Ethnicity:** 82% White, 12% Black, 6% other. **School grade:** not reported. **SES:** 25% classified as "poor" (income-to-needs ratio - ITN < 1), 25% "near poor" (ITN < 2). The other 50% had ITN ≥ 2, with nearly half of these having ITN > 4**.** **Country/region of origin:** USA**.**	(PDS; Petersen et al., 1988).	(MSIT; Bush et al., 2003).	structural equation model.	performance were found when adjusting for age.
Ellis, 2002	Cross sectional.	165	**Age**: mean(SD) = 12.31(1.58) years **Sex**: Both. 77 females; 71 males **Ethnicity**: presumed white by the authors. **School grade**: not reported. **SES**: not reported. **Country/region of origin**: USA.	**Body Changes Questionnaire**, parent- and self-reported, a scale adapted from Carskadon and Acebo (1993), based on the PDS (Petersen et al., 1988).	**Early Adolescent Temperament Questionnaire - Revised** (EATQ-R; Ellis and Rothbart, 2002), self- and parental report, using the Effortful Control subscale of the further subdivided in subscales for attention, inhibitory control and activation control, (mostly) independent of socioemotional contexts.	Adjusted for age in the correlation analyses by calculating partial correlations.	For girls, there were significant, negative, small correlations between pubertal status adjusted for age and self-reported attention, inhibitory and effortful control subscales (worse self-control), and parent report or inhibitory and activation control (but not attention). No pubertal effects were found for males when adjusting for age.
Gorday and Meyer, 2018	Cross sectional.	99	**Age**: range = 8-14 years. **Sex**: females only. **Ethnicity**: not reported. **School grade**: not reported. **SES**: not reported. **Country/region of origin**: USA.	**Pubertal Development Scale** (PDS; Petersen et al, 1988), self- and parent-reported. **Salivary concentrations of estradiol, progesterone, DHEA and testosterone,** assessed using enzyme immunoassay kits.	**Go/No-go task**.	Adjusted for age in the correlation analyses by calculating partial correlations.	No effects of PDS or pubertal hormones on task performance were found when adjusting for age.

Graber et al., 2006	Cross sectional.	100	**Age**: mean(SD) = 12.13(0.8) years; range = 10-14 years. **Sex**: females only. **Ethnicity**: white. **School grade**: 5th to 7th grade. **SES**: Most participants' families (96%) were in the two highest Hollingshead social classes. **Country/region of origin**: USA.	**Blood levels of DHEAS**, measured using radioimmunoassay kits. **Metrics:** The study seem to have used DHEAS concentration as a continuous variable.	**A 5-item Attention scale was created based on items taken from the Youth Self-report** (YSR; Achenbach and Edelbrock, 1986).	Age was included as a covariate in the analyses.	No effects of DHEAS on questionnaire scores were found when adjusting for age.
Herlitz et al., 2013/ Lovén, 2012	Cross sectional.	187	**Age**: range = 12-14 years. **Sex**: both. 85 males and 102 females. **Ethnicity**: not reported. **School grade**: varied, but not reported in detail. **SES**: recruiting procedure was designed so that sample would be homogeneous with respect to socioeconomic background (upper middle class). **Country/region of origin:** Sweden.	**Tanner stages, self-reported using text and schematic drawings developed for clinical use** (Hall & Pilström, 1996, 1999). **Blood levels of estradiol and free-testosterone**, measured using fluoroimmunoassay kits.	**Verbal fluency.** **Modified version of Vandenberg Mental Rotations Test** (Vandenberg, 1971).	Adjusted for age in the correlation analyses by calculating partial correlations.	There was a positive, small-to-medium partial correlation (adjusted for age) between mental rotation and estradiol for boys. No other effects were found when adjusting for age.

Icenogle et al., 2017	Cross sectional.	3,234	**Age:** mean(SD) = 12.87(2.36) years; range = 9-17 years. **Sex:** both. The proportions of male and female adolescents were nearly even within the whole sample (50.9% male, n = 1,650; 49.1% female, n = 1,709), within each country (range: 47.7%–53.5% female) and across ages. **Ethnicity:** varied, claimed to be representative of each country, but not reported. **School grade:** varied, not reported. **SES:** participants in each country came from households with similar levels of parental education, which averaged 'some college' **Country/region of origin**: participants came from 11 countries: Guang-Zhou and Shanghai, China (N = 321); Medellin, Colombia (N = 341); Nicosia, Cyprus (N = 233); Delhi, India (N = 240); Naples and Rome, Italy (N = 376); Amman and Zarqa, Jordan (N = 308); Kisumu, Kenya (N = 303); Manila, the Philippines (N = 309); several cities in the west of Sweden (N = 243); Chang Mai, Thailand (N = 321); and Durham and Winston-Salem, the United States (N = 364).	**Pubertal Development Scale** (PDS; Petersen et al., 1988).	**Modified version of the Iowa Gambling Task** (IGT; Bechara et al., 1994).	Adjusted for age including it in the statistical models.	There was a medium-sized, positive effect of PDS scores on the slope of the change in approach of the advantageous deck in the task (implying better performance). No other effects were found when adjusting for age.

Koch et al., 2020	Longitudinal, but relevant analyses are cross-sectional.	188	**Age**: mean(SD) = 11.75(1.05) years; range = 9–14 years. **Sex**: females only. **Ethnicity**: European American (83%), Southeast Asian (5.24%), East Asian/Pacific Islander (3%), American Indian/Native (2.25%), African American (1.87%), Hispanic/Latino (1.12%) and bi-racial or another race (3.37%). **School grade**: Varied. **SES**: 87% of parents who reported their education (N = 75) holding a bachelor's degree or higher. But most parents did not report schooling indicating reporting bias. **Country/region of origin**: USA. Of note, this seems to be the sample studied in Mendle et al., 2020.	**Pubertal Development Scale** (PDS; Petersen et al., 1988; Carskadon & Acebo, 1993).	**Ruminative Response Scale of the Children's Response Styles Questionnaire** (Abela et al., 2002; Abela et al., 2007).	Age was included as a covariate in the relevant structural equation models.	There was a small, positive effect of pubertal status on rumination scores, meaning increase of rumination.

Kretch and Harden, 2014	Cross sectional.	58	**Age:** mean(SD) = 13.6(1.67) years; range = 11-16 years. **Sex:** both. Male and female (50%). **Ethnicity:** African-American (63.9%), Hispanic (19.7%) and Caucasian (presumably 16.4%). School grade: not reported. **SES:** 76% of participants reported receiving free or reduced-price lunch at their school, indicative of low income. **Country/region of origin:** USA**.**	**Modified version of the Pubertal Development Scale** (PDS; Petersen et al., 1988), with separate scores for items related to gonadal hormones and items related to adrenal hormones.	**The Stoplight Game** (Chein et al., 2011; Gardner and Steinberg, 2005; Steinberg et al., 2008) played alone or observed by peers.	Age was included as a covariate in the statistical model.	There was an effect of pubertal status based on gonadal score, with a positive effect on the number of risky decisions (i.e., higher risk-taking) in the task irrespective of playing alone or with peers. There was a significant effect of equal direction and similar magnitude for adrenal scores on latency to wait only in the peer condition.
Laube et al., 2017	Cross sectional.	72	**Age**: mean(SD) = 12.34(1.17) years; range = 11-14 years. **Sex**: males only. **Ethnicity**: not reported. **School grade**: not reported. **SES**: not reported. **Country/region of origin:** USA.	**Salivary testosterone**, measures by unspecified method. **Pubertal Development Scale** (PDS; Petersen et al., 1988).	**An intertemporal choice task** (McClure et al., 2004; van den Bos et al., 2015).	Age was included as a covariate in the statistical model**.**	There was a small-to-medium, positive effect of testosterone on the proportion of smaller and sooner choices (higher impulsiveness) in the task. No other effects were found when adjusting for age.
Laube et al., 2020	Cross sectional.	70	**Age**: mean(SD) = 12.56(1.64) years; range = 11-15 years. **Sex**: males only. **Ethnicity**: not reported. **School grade**: not reported. **SES**: not reported. **Country/region of origin**: Germany.	**Salivary testosterone**, measures by ELISA.	**An intertemporal choice task** (Rodriguez et al., 2015; van den Bos et al., 2015).	Age was included as a covariate in the statistical model**.**	There was a small-to-medium, positive effect of testosterone on the bias for smaller and sooner choices in the task (higher impulsiveness). No other effects were found when adjusting for age.
Lee and Rasmussen, 2022	Cross sectional.	28	**Age**: mean(SD) =11.21(0.44) years; range = 9-16 years. **Sex**: both. 8 females, 20 males. **Ethnicity**: 25 (89.3%) White, 2 (7.1%)	**Tanner staging criteria** (Marshall and Tanner, 1969, 1970), assessed by a physician.	**Delay discounting** was assessed with two tasks: **Food Choice Questionnaire**	Age was included as a covariate in the	No effects of pubertal status on discounting variables were found when adjusting for age.

			Hispanic/Latino, 1 (3.6%) Asian. **School grade**: not reported. **SES**: not reported. **Country/region of origin**: USA		(FCQ; Hendrickson et al., 2015; Hendrickson & Rasmussen, 2017). **Monetary Choice Questionnaire** (MCQ; Kirby & Marakovic, 1996; Kirby et al.,1999).	statistical models**.**	
Mathias et al., 2016	Longitudinal.	153	**Age (at baseline)**: mean(SD) = 11.44(0.9) years; range =10-12 years. **Sex**: males only. **Ethnicity**: "predominantly Hispanic ethnicity and White race" **School grade**: not reported. **SES**: not reported. **Country/region of origin**: USA.	**Pubertal Development Scale** (PDS; Petersen et al., 1988; Carskadon & Acebo, 1993).	**The Two Choice Impulsivity Paradigm** (TCIP; Dougherty et al., 2005). **The Immediate Memory Task** (IMT; Dougherty et al., 2002). **The GoStop Impulsivity Paradigm** (GoStop; Dougherty et al., 2008; 2005).	Adjusting for age by including it in the model for the longitudinal analyses. The paper also had cross-sectional analyses, but these did not adjust for age.	There were longitudinal differences in the proportion of smaller-sooner responses in the delay discounting task between groups with different pubertal trajectories (faster pubertal trajectory associated with higher impulsiveness in the task performance trajectory). No other effects were found when adjusting for age.

Mendle et al., 2020	Cross sectional.	228	**Age:** mean(SD) = 11.75(1.05) years; range = 9–14 years. **Sex:** females only. **Ethnicity:** European American (79.2%), Southeast Asian (2.21%), East Asian/Pacific Islander (2.21%), American Indian/Native (3.54%), African American (2.21%), Hispanic/Latino (3.98%), and biracial/another race (6.64%). **School grade:** varied**.** **SES:** 87% of parents who reported their education (N = 75) holding a bachelor's degree or higher. But most parents did not report and there is evidence of reporting bias. **Country/region of origin:** USA. Note: this seems to be the sample studied in Koch et al. (2020).	**Pubertal Development Scale** (PDS; Petersen et al., 1988; Carskadon & Acebo, 1993).	**Negative Urgency subscale from the UPPS-P Impulsive Behavior Scale for Children** (Zapolski et al., 2010). **Ruminative Response Scale of the Children's Response Styles Questionnaire** (Abela et al., 2002; Abela et al., 2007).	Age was included as a covariate in the relevant structural equation models.	There was a small, positive effect of pubertal status on rumination scores when adjusting for age There were no direct effects of pubertal status on negative urgency when adjusting for age.
Ng-Night et al., 2016	Longitudinal.	750 at wave 1, 1712 at wave 2 and 1653 at wave 3.	**Age (at baseline)**: mean(SD) = 11.25(0.29) years. **Sex**: both. 54% female. **Ethnicity**: 40% from "minority ethnic groups" **School grade**: beginning secondary school at baseline. **SES**: 16% had "indicators of socioeconomic deprivation" **Country/region of origin**: United Kingdom.	**Pubertal Development Scale** (PDS; Petersen et al., 1988), self-reported. PDS scores were obtained in each of the three waves.	**13-item Brief Self-Control Scale** (BSCS; Tangney et al., 2004)), self-report. Self-control was assessed in each of the three waves of the study.	Adjusted for age by including it as a covariate in the structural equation models.	There was a small, negative effect of pubertal status at baseline on self-control at baseline. No other effects were found when adjusting for age.

Olson et al., 2009	**Cross sectional.**	**79**	**Age:** mean(SD) = 16.44(4.10) years; range = 9-23 years. **Sex:** both (53.2% female). **Ethnicity:** of 72 participants: Caucasian (68), African American (1), Hispanic (3), Asian/Pacific Islander (2), other (including multiracial) (4), and not reported (1**).** **School grade:** not reported. **SES:** varied; income mean(SD) = 91,493 (71,292). **Country/region of origin:** USA**.**	**Pubertal Development Scale** (PDS; Petersen et al., 1988).	**A delay-discounting task** (Richards et al., 1999).	Age was included as a covariate in the statistical models.	There were no effects of PDS scores on discounting parameter when adjusting for age.
Ordaz et al., 2018	Cross sectional.	78	**Age**: range = 11-13 years for females, 12-14 years for males. **Sex**: both. 34 females, 44 males. **Ethnicity**: 78% White, non-Hispanic, 14% Black, non-Hispanic, and 8% multiracial. **School grade**: not reported. **SES**: not reported. **Country/region of origin:** USA.	**Tanner staging criteria** (Marshall and Tanner, 1968), assessed by a nurse. **Blood levels of testosterone (for boys and girls) and estradiol (only for girls)**, using radioimmunoassay kits.	**An antisaccade task** (Hallett, 1978).	Age was included as a covariate in the statistical models**.**	There were no effects of pubertal status or hormone levels on accuracy in the task when adjusting for age.
Steinberg et al., 2008	Cross sectional.	417	**Age**: range = 10-16 years. **Sex**: both. 231 males and 186 females. **Ethnicity**: 30% African Americans, 15% Asians, 21% Latino(a)s, 24% Whites, and 10% others in the whole sample (ages 10 to 30). Not reported for the subsample of interest. **School grade**: not reported. **SES**: "predominantly working and middle class". Assessed via parent's education. **Country/region of origin**: USA.	**Pubertal Development Scale** (PDS; Petersen et al., 1988).	**The Stoplight Game** (Gardner and Steinberg, 2005).	Age was included as a covariate in the statistical models**.**	Pubertal status had a positive effect on the number of intersections crossed successfully in the task (better performance). No other effects were found when adjusting for age.

Sullivan et al., 2016	Cross sectional.	692	**Age**: range = 12.0 to 21.9 years. **Sex**: both. 344 male and 348 female. **Ethnicity**: most participants were Caucasian (486), African-American (87) and Asian (52). **School grade**: Not reported. **SES**: years of parental education, mean(SD)~16.8(2.5). **Country/region of origin**: USA.	**Pubertal Development Scale** (PDS; Petersen et al., 1988).	University of Pennsylvania Web-Based Computerized Neurocognitive Battery (WebCNP; Gur et al., 2012; Gur et al., 2010) including composite scores for speed and accuracy in abstraction (including conditional exclusion, matrix and logical reasoning), attention (including various measures of a continuous performance task) and working memory (various measures of a visual N-back task). A delay-discounting task (Stanger et al., 2012).	States that analyses were performed to evaluate effects of pubertal development independent of age, but no details are given.	No independent contributions of age versus PDS to performance were found.
Vannucci et al., 2014	Cross sectional.	468 or 122, depending on the analysis.	**Age:** mean(SD)=14.01(2.53) years, rage=8–17 years. **Sex:** both.53.4% female. **Ethnicity:** 58.1% non-Hispanic White, 33.3% non-Hispanic Black or African American, 5.9% Hispanic/Latino, 2.3% Asian Origin, and 1.4% Multiple Races. **School grade:** not reported. **SES:** not reported. **Country/region of origin:** USA.	**Tanner breast staging criteria for girls and Prader testicular volume standards for boys** (Marshall and Tanner, 1969, 1970; Tanner, 1981), assessed by endocrinologist or trained nurse.	**Objective and subjective binge episodes (OBE and SBE, respectively) with loss of control, assessed with the Eating Disorder Examination (EDE), versions 12.0D and C.2** (Fairburn and Cooper, 1993; Bryant-Waugh et al., 1996).	Age was included as a covariate in the statistical models**.**	There were no effects of PDS on outcomes of interest when adjusting for age.
Vetter et al., 2013	Cross sectional.	60	**Age**: mean(SD) = 13.86(0.92) years; range = 12-15 years.	**Pubertal Development Scale** (PDS; Petersen et al., 1988),	**Story Comprehension test** (Channon & Crawford, 2000), a	Age was included as a covariate in the statistical models**.**	There were no effects of PDS on outcomes of interest when adjusting

			Sex: both (23.3% male). **Ethnicity**: not reported. **School grade**: 7th and 8th grades. **SES**: not reported. **Country/region of origin**: Germany.	self-reported German version (Watzlawik, 2009).	theory of mind task translated into German.		for age.
Waber et al., 1985	Longitudinal, but relevant analyses are cross-sectional.	145	**Age**: mean(range) = 127.41(120-134) months for females and 153.4(145-162) months males. **Sex**: both. 78 females and 67 males. **Ethnicity**: white **School grade**: 5th grade (females) and 7th grade (males). **SES**: fathers' occupations were rated according to the Hollingshead system. Of the 90% of the girls for whom parental occupation was known, 93% were classified as upper to upper-middle class. Similarly, for the boys, of the 91% for whom parental occupation was known, 89% were classified as upper to upper-middle class. **Country/region of origin**: USA	**Tanner staging criteria** (Tanner, 1962), assessed by a physician.	Several cognitive tests: **Stroop Color-Word Interference Test; Wechsler Intelligence Scale for Children-Revised (WISC-R) Coding Subtest; WISC-R Block Design; Primary Mental Abilities (PMA) Spatial Test; PMA Word Fluency Test.**	Age was included as a covariate in the statistical models**.**	There were negative, statistically significant correlations (adjusted for age) between pubertal status and scores adjusted for age for coding and block design for females. However, the magnitude of the adjusted correlations was not reported and these correlations could only be found when separately analyzing data for participants from one of the two study towns.

Warren and Brooks-Gunn, 1989	Cross sectional.	100	**Age:** mean = 12.1 years; range = 10.6-13.3 years. **Sex:** females only. **Ethnicity:** only White. **School grade:** 5th-7th grade. **SES:** middle to upper-middle class. Ninety-six percent of the families were in the two highest of the five Hollingshead social classes. **Country/region of origin:** USA.	**Tanner staging criteria** (Marshall and Tanner, 1969), assessed by a nurse or physician. Blood levels of **LH**, **FSH**, **prolactin**, **estradiol**, **testosterone**, and **DHEAS**, measured by radioimmunoassay.	**Impulse Control subscale of the Self Image Questionnaire for Young Adolescents** (SIQYA; Petersen et al., 1984).	Age was included as a covariate in the statistical models.	There was a significant quadratic relationship between impulse control scores with stages based on hormonal concentrations. Impulse control decreased between hormonal stages I and II, and increased between II-III and III-IV. No other effects were found when adjusting for age.