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Interdisciplinary Work Is Essential for Research on Puberty: Complexity and Dynamism in Action

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Abstract

Puberty is associated with changes in behavior and psychosocial well-being, and is important in lifelong health. We present five different facets regarding interdisciplinary research that are important to puberty. A short history of philosophical issues instrumental in promoting early interdisciplinary research is first presented. We discuss then what is hard and what is easy about interdisciplinary research, the purpose of which is to alert scientists to challenges and opportunities for interdisciplinary research on puberty. Readers then are introduced to advances and obstacles in interdisciplinary research on development. Recommendations for tailoring graduate education toward interdisciplinarity are introduced. Finally, issues related to publication, education of scientists, and policy makers are described. The report concludes with a discussion of funding and policy issues.

The topic of puberty is inherently interdisciplinary, given that it entails major biological, social, and macroenvironmental level (family, school, and neighborhood) influences and changes during the transition from childhood to adolescence. Puberty is a result of multiple determined prenatal genetic and hormone influences that result in reproductive maturation. Puberty entails an intricate series of multiple hormone, growth, and social changes. The complexity of dynamic and related change across and between biological, social, and psychological contexts presents scientists with an intriguing yet challenging task for doing interdisciplinary research. This complexity requires intricate theoretical models and presents notable practical challenges which have impeded concerted efforts to describe mechanisms of biological and behavioral changes at puberty. Any one discipline or scientist is ill-equipped to consider it in its full complexity because puberty is multidetermined, involving many systems. Fortunately, in the 1980s a group of scientists adopted an interdisciplinary approach to answer perplexing questions about the simultaneous development between

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pubertal–biological processes involving increases in gonadal and adrenal hormones and behaviors (e.g., depression symptoms, aggression) (Brooks-Gunn & Warren, 1989; Susman et al., 1987) and sexuality (Halpern, Udry, & Suchindrand, 2000). Despite growing interdisciplinary research, currently the integration of biological and psychological sciences continues to be laden with unsolved problems, including conceptual, analytic, and logistical challenges. With these perplexing issues as a backdrop, this report will focus on (1) a short history of interdisciplinary work on puberty; (2) a description of what is hard and what is easy about interdisciplinary research on puberty; (3) the major advances and continued obstacles that have resulted from interdisciplinary work thus far; (4) recommendations for tailoring graduate education to think interdisciplinarily in training current and future generations of scientists; and (5) issues related to publication, education, and solicitation of related disciplines to advance research. This report will conclude by discussing implications for a positive future for interdisciplinary research and its relationship to policy.

A SHORT HISTORY OF INTERDISCIPLINARY WORK ON PUBERTY AND THE KINDS OF INTERDISCIPLINARY WORK THAT ARE NEEDED TO DESCRIBE AND EXPLAIN THE MULTIPLE COMPONENTS OF PUBERTY

Interdisciplinarity and multidisciplinarity in research and education involve the bringing together of two or more academic disciplines into an activity or entity. An interdisciplinary approach is based on the idea that convergence brings unity and synthesis (Klein, 1990). As such, interdisciplinary research strategies involve creating something unique by threading together academic disciplines like medicine, psychology, and statistics. In contrast, multidisciplinary research strategies draw disciplines and collaborating scientists together, but do not necessarily integrate the multiple components of the research effort into an overarching theory or interpretation of findings. The study of puberty has required an interdisciplinary approach where theories, methods, analyses, and interpretations from adolescent medicine, endocrinology, nursing, psychiatry, psychology, and other fields are intertwined to synthesize description and explanation of the phenomena of puberty.

History

The history of interdisciplinary work on puberty extends from Greek scholars onward. As far back as Plato, philosophers, historians, and poets have been discussing the unity of human puberty involving brain, behavior, and emotions (Nye, 2015). The theories regarding the extent to which mind and brain are coordinated have waxed and waned for the last four centuries. Cartesian dualism, for instance, espoused that the mind and body were completely separate (Robinson, 2003). However, as the scientific approach took hold and evidence linking mind and brain grew, dualism eventually was replaced with a more holistic view. By the 19th and early 20th centuries, researchers like Hans Selye (1973) and Anna Freud (1966) were regularly espousing the dynamic and ongoing links between the mind and particular illnesses and disorders. The integration of mind and body continues on, and is reflected in the emergence of new interdisciplinary fields like neuroscience.

Despite the ongoing advancement of theories connecting mind and body, puberty has not always been conceptualized as a holistic and coordinated mind-body process. Even in the

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1960s, studies generally emphasized a physiological perspective of mind plus body development derived from animal models, or, when taking a psychological perspective of development derived from observation of humans, maintained a view of puberty as atypical or pathological. Understanding of puberty was disjointed.

For the last several decades, though, researchers of adolescent development have been working to integrate knowledge of the physiological and psychological changes that occur during puberty into a more unified and holistic model of pubertal and lifespan development (Kipke, 1999). Knowledge of biochemical and physiological changes in adolescent development informed study of how the timing and tempo of puberty influences psychological development (Brooks-Gunn & Peterson, 1983; see also Petersen & Leffert, 1995). Endocrinologists focused on the biological, hormone, and growth changes of puberty whereas psychologists focused on behavioral changes of puberty to describe the interrelations of depression and aggression with estrogen and testosterone (e.g., Brooks-Gunn & Warren, 1989; Susman et al., 1987). This intertwining of disciplines led to new discoveries and a comprehensive description of the endocrine changes responsible for the onset and progression of puberty (Grumbach & Styne, 1998). Invigorated by the initiation of large-scale longitudinal studies that measured both physiological and behavioral change (e.g., Add Health; National Longitudinal Study of Adolescent Health, 2017), highly interdisciplinary (and translational) research that combined family intervention, genetics, neuroscience, and tracking of behavioral change (e.g., Brody et al., 2009) informed both basic and applied knowledge of how social, biological, and contextual changes contribute to normative pubertal development. Casting off the idea that puberty was atypical or pathological, the expanded knowledge prompted consideration of a strength-based view of adolescent development and how puberty contributes to positive youth development (see Lerner, Almerigi, Theokas, & Lerner, 2005; Vierimaa, Bruner, & Côt'e, 2018). Investigative teams now combine animal and human models, behavior genetics, and neuroscience tools (see Aylwin, Toro, Shirtcliff, & Lominiczi, 2019, in this issue). As the momentum for interdisciplinary science carries forward, we present some recommendations for where that energy might be directed.

What Is Now Needed?

Broadening the models and questions.—To achieve interdisciplinary integration, the various domains of puberty science need to be more thoroughly expanded from focus on single domains of function to simultaneously focus on multiple domains of functioning (e.g., genetic variation, brain development, hormones, cognitive function). Although study of specific alleles, hormones, or social contexts is pragmatic and enables detailed description, isolated studies cannot capture the full landscape of puberty. For example, no one hormone explains more than a small percentage of the variance in behavior at puberty (e.g., Susman et al., 2007). Our concern is that when specific theories, techniques, research designs, or pathways are emphasized, perhaps even prioritized, interpretation of the findings is necessarily limited, interdisciplinary input lost, and the full landscape of puberty underdescribed. In contrast, a priori inclusion of different disciplines and widening of the research frame broadens questions, theoretical models, and interpretation of empirical results in ways that promote more robust description of puberty. Although it may not be

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possible to consider or actually model the massive number of inputs and outputs in the human interactions and dynamic hormone-behavior systems that influence puberty (see Si, Barto, & Donald, 2004), systematic and consistent expansion of models can both keep the task manageable and provide for integrated discovery of the processes that influence and drive puberty.

Integrating New Methodological Issues

The rapidity and complexity of puberty presents intriguing methodological and statistical problems and possibilities worthy of multiple papers and books but our discussion is necessarily constrained by the publication format. We urge readers to seek to advance methods of inquiry and encourage readers to continue to make methodological advances while attempting to spark ongoing interests in interdisciplinary methodological collaboration in the future (see Marceau, Ram, Houts, Grimm, & Susman, 2011). As already noted, puberty is a developmental process that spans multiple levels of analysis. As such, the study of puberty requires conceptualizations and analytical models that can accommodate interlocked and intertwined neurobiological, physical, psychological, and social growth processes. Complicating the task is that the observable outcomes of interest (e.g., hormone levels, neuronal structures, physical characteristics, psychological states, and behavior) are all multidetermined. For example, an adolescent's level of circulating testosterone is driven by genetics, responses to stress, circadian rhythms, eating, sleep, and changes in context (Ojeda & Terasawa, 2002). Parsing these influences and the time scales on which they proceed will require adoption and adaptation of a new arsenal of multivariate and longitudinal methods that have emerged alongside advances in technology and computation (see Mendle, Beltz, Carter, & Dorn, 2019, in this issue). This new arsenal has several components. We highlight eight considerations that interdisciplinary scientists might consider as they locate and integrate data with theoretically guided research questions.

Theory-informed models.—Across disciplines, scientists are using theory-informed models to simulate behavior of particles, animals, and humans, an inherently interdisciplinary endeavor. In computational biology, for instance, scientists simulate physiological and chemical processes that provide potential explanations of phenomena in the real world. Engaging in-silica (fully computer-based) experiments, simulation engines allow scientists to discover the processes, time scales, and influences that underlie the nonlinear relations observed in empirical data. In particular, simulation models increase our ability to quickly rule out theoretical models that are unable to produce outcomes or trajectories that are similar to observed data. Advances in computational speed provide new opportunities to thoroughly examine the viability of specific hypotheses. For example, simulations might be used to identify the type of feedback loops a hypothetical biological system would need in order for family influences (e.g., father absence, family disruption, parental investment [Belsky & Pluess, 2009; Ellis, Boyce, Belsky, Bakermans-Kranenburg, & van Ijzendoorn, 2011; Ellis, Shirtcliff, Boyce, Deardorff, & Essex, 2011]) to promote or delay pubertal development. While these simulated systems would most certainly only be approximations of a real endocrine system, the knowledge gained would inform both the kind of data we collect and how we might analyze these data. Following the innovations made in computational biology, and how they have informed global food production, we can

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more quickly explore how biopsychosociocultural inputs are able to produce the full range of outcomes and trajectories we see in the world.

Longitudinal designs.—Of course, in addition to making use of existing data, the need for additional interdisciplinary, longitudinal studies of puberty-related changes and adult sequelae is ever present. Identifying very early puberty changes and life events and consequences requires possession of long-term data. Animal models are particularly useful in this endeavor because the lifespan of most subhuman species is much shorter than that of humans (see Aldwin et al., 2019, in this issue). The good news is that several long-term studies of humans are now yielding important findings. Examples include community-based studies of typical and atypical youth in global contexts such as the Young Lives Cohort Study (UNICEF), The National Longitudinal Study of Adolescent to Adult Health (Add Health), and the Study of Early Child Care and Youth Development (SECCYD). In conclusion, without doubt deeper understanding of puberty and its antecedents and consequents requires a robust toolbox of longitudinal interdisciplinary theories, designs, analytical methods and much, much more data. An example of needed longitudinal research are studies that identify the onset of puberty while also tracking behavior change in relation to changes in the endocrine parameters in early puberty. The appearance of external secondary sex characteristics does not necessarily indicate the onset of puberty, given that there is a time lag between hormone changes and external presence of pubic hair and breast and genital growth. Defining the onset of puberty is an important issue because early brain changes of puberty, or lack of changes in hormone and growth parameters, may identify early problems that if found early can be remediated in high-risk groups.

Within-person process.—Puberty is by definition a within-person process. As such, it will be useful to shift inquiry from study of between-person differences toward explicit study of within-person processes (Ram & Gerstorf, 2009). This approach will explicitly prioritize description and explanation of how individuals make their way through puberty. Aligning insights from ethnographic research conducted by anthropologists (e.g., the subjective, psychological, and social perspectives) and computational biology, genetics, and animal models may be particularly useful for developing theories of the within-person processes of puberty. Only after obtaining detailed knowledge of intraindividual change sequences can we “realign” those developmental sequences in ways that allow for accurate comparisons across persons. That is, we can assess developmental sequences by lining up the event or sequence across individuals (e.g., coding our unit of time as time to and from a specific event or sequence of interest). For example, only after describing the nonlinearities in individual growth trajectories was the field able to realign those trajectories in ways that highlighted the homogeneity of the pubertal growth spurt (Marceau et al., 2011; Susman et al., 2010). A major remaining question is whether one can align the internal biological changes of puberty (e.g., change in gonadal steroids and adrenal androgens) with the external growth changes (Huang et al., 2012). If we are successful in realigning endogenous and exogenous indices of puberty, then the easily collected physical growth exogenous measures will become a more acceptable and less expensive index of the endogenous characteristics of puberty. In brief, we see that dynamic time-warping methods (a strategy used in time-series analyses for measuring the similarity between two temporal/

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developmental sequences that vary) will be particularly useful in integrating models of intraindividual change with examination of interindividual differences in intraindividual change.

Deterministic versus stochastic models.—Most of the models used by social scientists in analysis of pubertal changes are deterministic rather than stochastic. That is, the "error" terms are considered as misfit or unexplained differences, rather than as the milieu of biopsychosociocultural inputs that actually drives the organism. It may be useful to more explicitly consider how "stochastic variance" that manifests both internally and externally (e.g., random encounters between cells or persons) may be provoking adaptive systems into change or stability maintenance. An instance of the importance of stochastic variance is the typical pulsatile secretion of gonadotropin-releasing hormone (GnRH). Gonadotropin-releasing hormone neurons regulate reproduction though pulsatile hormone secretion (Dulka & Moenter, 2017). Models that require advanced stochastic variance modeling necessitate the expertise of senior methodologists/statisticians working along with behavioral and biomedical interdisciplinary scientists.

Nonlinearity.—The study of puberty requires examining how and why individuals change in different ways. Considering the central role that biology plays in the timing, tempo, and sequence of the neuronal, physical, and psychological changes that constitute puberty, it seems essential to consider nonlinear models of change. While many researchers consider models of linear change because of their simplicity and interpretability, pubertal processes are almost by definition characterized by nonlinearity. Changes in height across puberty, for example, are characterized by acceleration and deceleration (growth spurts and asymptotes) (Rogol, Clark, & Roemmich, 2000). Changes in hormone levels are both provoked and bounded by the affordances and constraints embedded in activation–inhibition feedback loops (e.g., gonadotropins). Interdisciplinary scientists should embrace and make use of more complex models that accommodate the nonlinear relations likely embedded in most puberty-related data streams (Grimm, Ram, & Hamagami, 2011). Movement away from inaccurate linear models and toward more realistic nonlinear models will be facilitated by both modern data collection methods (rapid repeat of assessments) and computing.

Notion of time.—The interdisciplinary study of puberty might de-emphasize the existing notions of "time" (e.g., age). Although the notion of time has been incorporated in various ways in studies of pubertal development, the meanings and measures of time deserve further attention. Seasons and months may hold meaningful value from an evolutionary standpoint, as indicated by the linking of puberty to early evolution of organisms related to the seasonal variation, diurnal variation, and lunar cycles (Matchock, Dorn, & Susman, 2007), but it is difficult to consider time as a "cause" of development. Further, the time metrics we usually rely on may or may not be linked to specific time scales (e.g., Tanner stages; Marshall & Tanner, 1969, 1970), particularly distinct or defined (e.g., residualizing age for age-at-menarche), or provide for identification of specific patterns of change (e.g., sequencing, timing and tempo). Our general suggestion is to measure the physical and psychological components of puberty much more often (weekly/daily). The increased density of data will support discovery of the actual time scales on which pubertal changes manifest. Although

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expensive and time-consuming, the adoption of more intensive repeated measures designs (e.g., every three to six months) allows for a shift away from examination of only slow time-scale changes (e.g., in individuals' level of testosterone) and toward examination of intraindividual variability. For example, fluctuations in hormones during puberty may promote intraindividual variability in individuals' emotional experience (Peeters, Nicolson, & Berkhof, 2004)—a phenomenon that would be totally missed when only a few widely spaced measurements are available. Given that many physiological systems are structured around modulation of "noise" (e.g., frequency modulation), it seems likely that much of the hormone signaling (e.g., via receptors, second order signals, and minute-byminute pulsatile-secretion) that surrounds pubertal changes can only be studied using intensive longitudinal data.

Data sharing.—A combination of factors, including modeling the complexity of puberty, funding agency requirements, and computerized databases have led to increased data sharing. Although it has been noted that some disciplines, including the psychological, social, and health sciences, are less likely to share data for various reasons (including ethical concerns about the right to share human data (Tenopir et al., 2015; Wartella, Rideout, Montague, Beaudoin-Ryan, & Lauricella, 2016), scientists are generally responsive to requests to share data in order to advance science (van Panhuis et al., 2014). The general view is that the scientific principles of ethical recruitment, data management, and maximizing research investment do apply to shared data (Poline et al., 2012). By sharing data, interdisciplinary work can be seeded without the need for significant heavy investment in new data collection. Interdisciplinary teams engaged in integrative data analysis can extract additional value from the significant accumulation of research data (Bainter & Curran, 2015). Pooling data from multiple studies increases statistical power (and generalized inference) and enables the testing of models that would be impossible to examine well in the individual source studies (Hofer & Piccinin, 2009). Together, the collection of existing longitudinal studies increases our capacity to examine the interactions among genetic, biological, familial, environmental, economic, social, and behavioral factors related to puberty. There are of course some challenges to overcome (Bauer & Hussong, 2009). For example, not all studies include standard measures of pubertal maturation (e.g., Tanner criteria; see Dorn & Biro, 2011; Dorn, Dahl, Woodward, & Biro, 2006). However, when we do find ways to link the data from different studies together, existing data will propel interdisciplinary understanding of puberty (Mendle et al., 2019, in this issue).

New data streams.—Often, accurate representation of nonlinear relations requires rich, interdisciplinary data streams, particularly when one is still discovering the "shape" of the change trajectory and the time scales on which change proceeds. Technological advances in the digitization of information/communication create the possibility to obtain more and more detailed data about both biology and behavior. New RNA transcription technologies provide for repeated observation of molecular processes. Recent advances in ambulatory assessment of steroid hormones (e.g., Miocevic et al., 2016), along with the potential of secure electronic transmission of digital records of physical changes, indicate the potential for measuring the biological changes of puberty in situ. Networking and mobile communication technologies provide the possibility to observe many aspects of individuals' and adolescents,

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in particular, behavior, more and more of which has become digitally mediated. Modern data mining methods are already being unleashed on these data (e.g., social media) to understand what adolescents do, to help them achieve their goals, and also to influence their future (e.g., purchasing) behavior. “Big data” corporations are in many ways “ahead of the game” in integrating rich data about how individuals move through the physical and virtual worlds. Advances in computational speed are facilitating interpretation, modeling, and prediction of aspects of human behavior. Applications that further our understanding of puberty are within reach—but will require deployment of new disciplines, data collection technologies, creative fusion of data streams from multiple sources, and adoption of computationally intensive analytical paradigms.

WHAT IS HARD AND WHAT IS EASY ABOUT INTERDISCIPLINARY RESEARCH ON PUBERTY

What Is Hard?

Each discipline has a plethora of variables and processes critical to understanding how particular behavioral variables might be related to hormones and growth at puberty. Endocrinologists begin with a set of hormones, like testosterone and estrogen; psychologists begin with a set of cognitive or social variables at either the individual, family, or macroenvironmental levels. Deciding how these components fit together is the daunting aspect of interdisciplinary research. While “the bucket of everything” approach—measure everything all the time—to interdisciplinary research is tempting, forward progress is often better served by coordinated conceptualization and careful measurement. By way of example, consider how interdisciplinary teams have approached and studied the effects of family conflict on youth development (Brody et al., 2009; Margolin, Ramos, Timmons, Miller, & Han, 2016). The aim in the Margolin study was to identify a) factors that make young adults more likely to behave aggressively toward a dating partner; and (b) ways that dating aggression spills over into couples’ everyday interactions. The research team brought together expertise in family systems—and the ability to observe and record family conflict [coded for specific behaviors and emotions (Spies, Margolin, Susman, & Gordis, 2011) and biological systems—and the ability to obtain and assay cortisol and salivary alpha amylase (sAA) from saliva obtained during family conflicts. Complementary expertise in peer and social relations highlighted several factors that buffer the associations between family conflict and physiology, such as affiliating with prosocial peers and having high levels of empathy and perspective taking (Han & Margolin, 2016; Margolin et al., 2016). A history of adversity and aggression appears to be associated with a dampening overall of physiological arousal reactions which when annoyed are somewhat heightened. Moreover, partners’ physiologies can be linked with each other, under both highly positive and highly negative circumstances. As the study progresses, it will be possible to find atypical longitudinal patterns of physiology and family conflict that will yield translation into interventions applicable to families with conflict. While these findings represent only a small set of findings emerging from a single interdisciplinary team (see also Arbel, Rodriguez, & Margolin, 2016; Gordis, Margolin, Spies, & Susman, 2010; Margolin, Spies, & Baucom, 2012), the program of research illustrates the utility of simultaneous assessment in multiple domains—conflict, stress, functioning of the HPA system, brain development (Saxby,

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Margolin, Spies Shapiro, & Baucom, 2018). Essential for success in these interdisciplinary studies is that researchers patiently and deliberately decipher the language and terminology of one another's disciplines. The challenge of coordinating efforts to bring together disciplines can be solved by coordination between editors, scientists, and students.

The Easy Side

Scientists by nature are stimulated by the intrinsic and applied value of research, and interdisciplinarity can support this excitement through long, collaborative, and elaborate studies. Puberty has characteristics that make it an easy meeting point: (1) the extent of within-person change occurring during puberty is massive and much easier to see than many other phenomena, and (2) there is a homogeneity of process in that all individuals go through puberty. These two facts make puberty much easier to study than phenomena that only affect a small population of persons. In a scientific zeitgeist that favors inclusion of both biological and psychological components, significant progress has been made in the funding and publication of biobehavioral studies of puberty (Dorn & Biro, 2011). The evidence accumulated to date is motivating involvement of many types of investigators. Interdisciplinary approaches now can incorporate molecular genetics, microbiomic assessments, neuroscientific theories, and multivariate methods.

MAJOR ADVANCES AND CONTINUED OBSTACLES IN INTERDISCIPLINARY WORK ON PUBERTY

Advances

Theoretical, technological, and methodological advances mentioned throughout this report reveal new vistas for examining the experiences and process of puberty. These advances include animal models, genetics and epigenetics, neuroimaging, microbiome, and neuroendocrine research, as well as internet-based (e.g., Cousineau et al., 2010) and life-logging approaches (Dobbins, Merabti, Fergus, & Llewellyn-Jones, 2012). Collaborations between these fields and human sciences are now beginning to take place, a promising trend. Overall, there are nascent opportunities for researchers fluent in the nuances and complexities of pubertal development to collaborate on new models or to use newer technologies to evaluate extant models.

Diving into some of the specifics, we highlight how interdisciplinary work on the psychobiology of stress has pushed knowledge of puberty forward. This field grew out of endocrinology, psychiatry, and neurobiology of stress (as indexed primarily by cortisol). With regard to stress in adolescents, since the late 1990s the hormone cortisol has been theoretically and empirically linked to stress, the primary glucocorticoid (e.g., Gunnar, Wewerka, Frenn, Long, & Griggs, 2009; Susman, Dorn, Inoff-Germain, Nottelmann, & Chrousos, 1997), transitions to middle school (Shirtcliff & Essex, 2008), normative changes during puberty (Gunnar et al., 2009; Stroud, Papandonatos, Williamson, & Dahl, 2004), and other substantive areas of inquiry. Furthermore, theories that join pubertal timing, cortisol, and family functioning represent a major advance in that these theories bring together anthropology, psychobiology, psychology, and pediatrics. As illustrative of this approach, Ellis and others (e.g., Belsky & Pluess, 2009; Boyce & Ellis, 2005) developed a model that

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proposes that adolescents are differentially sensitive to family stressors. These stressors in turn putatively affect the timing of puberty such that girls in conflictual families achieve earlier timing of puberty. The mechanisms involved in the stress-timing of puberty hypothesis are speculated to be conflictual family dysfunction, genetics, nutrition, and father absence. The linking of the hypothalamic–pituitary–gonadal (HPG) reproductive axis and the hypothalamic–pituitary–adrenal (HPA) stress axis was a landmark in beginning to identify mechanisms connecting puberty and stress. These new perspectives primarily grew out of animal models.

Animal Model Research as an Instance of Advances in Interdisciplinary Research

Animal models can be used to rigorously test hypotheses and theories and strengthen interdisciplinary integration (see Aylwin et al., 2019, in this issue). Unfortunately, social and behavioral scientists have not adequately taken advantage of animal models to explain puberty processes, with some exceptions (e.g., Sameroff & Suomi, 1996). In an additional exception, Ahn et al. (2015) showed that puberty in female humans enhanced the risk of an outcome of multiple sclerosis, an autoimmune disease. In the same publication, a mouse model of puberty showed the influence of the development of central nervous system autoimmunity (i.e., autoimmune encephalomyelitis in mice), supporting the role of the immune system in both humans and mice. However, although genetically influenced traits may be shared in animals and humans, genes may work in different ways in humans and animals. Plant's animal model work on puberty illustrates where there has been successful integration acros animal and human work related to puberty (Plant & Dubey, 1984). In rhesus monkeys, Plant and colleagues demonstrated that the network of hypothalamic GnRH neurons, which in adulthood provide the drive to the gonadotropin-secreting cells of the anterior pituitary gland, must now be viewed together with the pituitary and gonads as a nonlimiting component of the regulation system that governs the onset of puberty in various species (Plant, Rast, Gay, Marshall, & Arslan, 1989). In addition, Plant and Ramaswam (2009) reviewed the literature to assess the role of kisspeptin-GPR54 signaling in the regulation of the hypothalamic–pituitary–gonadal axis in higher primates and kisspeptin-GPR54 similarity with human puberty. The review concludes with a discussion of the phenomenon of GPR54, a gene involved in the onset of puberty in rhesus monkeys and humans, and downregulation of this gene by continuous exposure to kisspeptin, a receptor involved with the onset of puberty, and GPR54's therapeutic implications. In addition, Plant and others' animal model scientists have proved instrumental in defining the circadian rhythms of gonadotropins for applicability in humans. Studies of the endocrine processes in monkeys with comparison to humans require a great deal of expertise sharing between endocrinologists and behavioral scientists, but comparison of human and animal pubertal processes across species is an especially important endeavor given that ethical issues preclude experimental studies in humans that can be done with subhuman primates. In the future, it may become the norm to include both sets of scientists in studies of puberty. A recent example of this effort is a special issue of Neuroscience and Biobehavioral Reviews on the adolescent brain (Spear & Silveri, 2016) which paired an animal and human model on the same topic for a number of relevant domains. Schulz and Sisk (2016) reviewed the organizing actions of adolescent gonadal steroid hormones on sex differences in brain and behavioral development in animals, and Gur and Gur (2016) reviewed puberty-related sex

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differences in brain and behavior in human adolescents. Indeed, animal and human models are often interpreted together in some disciplines—for example, prenatal influences on behavior problems (Knopik, 2009), cognitive neuroscience (Spear, 2011), personality (Gosling, 2001), and behavior genetics (as indicated by the myriad animal and human studies in the journal Behavior Genetics).

Genetics as an Instance of Advances in Interdisciplinary Research

An unprecedented advance in interdisciplinary research and puberty is the integration across disciplines and levels of analysis, which is illustrated by recent work in behavioral and molecular genetics. Behavioral and molecular genetics approaches have accumulated a vast body of knowledge relevant to puberty. Lists of genes related to puberty have been made by examining genes individually and collectively (F. R. Day et al., 2017; Gajdos, Henderson, Hirschhorn, & Palmert, 2010); specifically, behavioral and molecular genetics. The field of genetics, behavioral and molecular, has added substantial gains in knowledge of puberty and behavior. A preliminary review of the literature and biosystems databases yielded a potential 406 genes that may be linked to pubertal phenotypes. (Investigators are in the process of verifying the reliability of the evidence for each gene prior to publication of a pubertal gene set).

Genome-wide association studies (GWAS) have been highly successful in identifying single nucleotide polymorphisms marking structural variants in DNA that are related to puberty (e.g., F. R. Day et al., 2017; Elks et al., 2010; Fernandez-Rhodes et al., 2013; Perry et al., 2014; Tan et al., 2015), although other pubertal anthropomorphics (e.g., pubertal growth spurt, Tanner stages, age at voice breaking) have been assessed in boys and girls (Cousminer et al., 2013, 2014; F. R. Day et al., 2017). Further, many of the genetic influences identified are unlikely to be specific to age at menarche, but rather contribute to multiple pubertal phenotypes (F. R. Day et al., 2017; Tu et al., 2015) as well as to associations of puberty with other phenotypes, including behavior (e.g., Corley, Beltz, Wadsworth, & Berenbaum, 2015; Ong et al., 2011; Tan et al., 2015). Across samples and measures of puberty, the clear take-home messages of this work include (1) pubertal maturation is polygenic; with many variants contributing small effects; (2) genetic influences on puberty include small effects of genes with common variation as well as larger effects of rare variants; (3) many of the variants also predict other phenotypes, including adiposity and obesityrelated phenotypes, internalizing symptoms, and cancer risk.

All pubertal phenotypes examined thus far (e.g., secondary sex characteristics, timing, hormone levels) have proven to be heritable, though the range of heritability varies dramatically with sample and phenotype (e.g., van den Berg et al., 2006; Corley et al., 2015; Ge, Natsuaki, Neiderhiser, & Reiss, 2007; Li, Ji, Yang, & Zhuang, 2016; Mendle et al., 2006; Silventoinen, Haukka, Dunkel, Tynelius, & Rasmussen, 2008). Despite the clear importance of genetic influences, Perry et al. (2014) showed that 123 variants across 106 loci together only explained 2.7% of the variance in age at menarche. It is hypothesized that the missing heritability is attributable to gene–gene and gene–environment interactions, and the role of epigenetics (Cousminer, Wid'en, & Palmert, 2016). In line with these hypotheses, a burgeoning field is using more interdisciplinary measures and sources, including systems

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biology and computational methods, and bridging animal and human models in order to identify gene sets and hierarchy involved in puberty as well as epigenetic regulation of genetic influences on pubertal maturation and links with behavior (e.g., Cousminer et al., 2016; Lomniczi, Wright, & Ojeda, 2015; Lomniczi et al., 2013; Ojeda & Lomniczi, 2014; Ojeda et al., 2010; Roth et al., 2007). Future work uncovering the hierarchical, polygenic nature of puberty and investigating gene–environment interplay in the context of specific polygenic and epigenetic influences is likely to yield important information for our understanding of the normal variations in puberty and associations with a wide array of physical and behavioral phenotypes. This future work is only made possible through collaborations across disciplines. For example, molecular, systems, and computational biologists, endocrinologists, geneticists, behavioral geneticists, developmental scientists, and behavioral scientists all are needed to work collaboratively to understand puberty.

Despite these many gains, there are many more questions and gaps in this literature that need to be answered. For example, boys are less frequently included in genetic studies of puberty. Furthermore, ethnicity differences have been difficult to test, and many pubertal phenotypes have been excluded, in part because of difficulty in measurement (e.g., adrenarche), various aspects of maturational profiles like synchrony, or rate of pubertal changes that incorporate multiple milestones. Filling these gaps through interdisciplinary collaborations will undoubtedly lead to advances in understanding how multiple aspects of genetics underlying puberty and behavior contribute collectively to puberty as a whole and to unique components of the pubertal process as well as linkages between puberty and behavior.

Neuroscience and Other Areas as Advances in Interdisciplinary Research

Advances in the neuroscience of adolescent brain development are growing at an astounding rate (e.g., Braams, van Duijvenvoorde, Peper, & Crone, 2015; Saxby et al., 2016; Suleiman, Galv'an, Harden, & Dahl, 2017). Neuroscience has made notable advances in relation to understanding the transformative and interactive effects of brain and behavior at adolescence (e.g., Peper & Dahl, 2013; Sisk, 2017). Other areas of advancement include the human microbiome and its relationship with puberty and adolescent development (Allen, Dinan, Clarke, & Cryan, 2017; Neufeld, Luczynski, Oriach, Dinan, & Cryan, 2016), genomic and epigenetic models (e.g., J. Day, Savani, Krempley, Nguyen, & Kitlinska, 2016; Dungan, Clifton, & Steiner, 2006; Manfredi-Lozano et al., 2016), and research at the forefront of wearable technology and big data. These advances will be possible only with interdisciplinary teams of scientists (Goddings, Beltz, Peper, Crone, & Braams, 2018).

Continuing Obstacles

The continued obstacles to the interdisciplinary study of puberty consist of philosophical issues, garnering cooperative collaborations, and funding. Philosophical issues are rooted in the belief that each discipline/area of expertise has its own preferred theories and strategies of how to evaluate and measure pubertal maturation. Garnering cooperation among collaborators can be difficult especially in settings with traditional discipline-based academic departments. Investigators from some disciplines and departments are not likely to be fully schooled in the science of pubertal development. Thus far, the complexity of describing the multiple interactive faces of puberty and of modeling dynamic change that

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varies in pattern within and between people has forced scientists to gravitate to one area or one specific question at a time. For instance, an ongoing problem is determining the effects of increases in GnRH, a hormone responsible for the onset of puberty, on the gonadal axis (Plant & Shahab, 2002) and subsequent behavior. Early puberty changes in GnRH have not been accessible to behavioral scientists but likely result in changes in neurotransmitters that affect emotions (Dungan et al., 2006). Behavioral scientists have not had access to designs that allow endocrinologists to simultaneously assess pulsatile secretion in GnRH and moods and behavior. With the growing popularity and usage of mobile data gathering technology collecting, both types of data will likely be available soon. The gravitation toward either endocrinology or moods or behaviors, the domain of psychology, results in inherent risks of reductionism and models built by bolting together findings from one domain to another (pasting on) rather than a merging of findings.

Finally, funding is often difficult to obtain for large-scale longitudinal studies that necessarily span years (as is needed to capture variations in pubertal maturation) and are expensive. Some strategies for overcoming this obstacle may include making the importance of the work more visible, harnessing the current climate of excitement about interdisciplinary work to improve odds of receiving funding, and looking “outside the box” for new funding sources. Strategic funding for innovative research can leverage a mass of data at a critical juncture, but the resources needed to amass longitudinal data are monumental. Collaborations across research groups in different sites help to amass larger numbers of participants and expertise of investigators, which may be appealing to government and not-for-profit institutions. These new data streams may be exploited most readily by computer scientists, but if they are to be capitalized in puberty research, researchers of puberty, where possible beginning in academic graduate education, must seek to integrate information and methods from these data streams, and this necessitates crossing the boundaries of disciplines.

RECOMMENDATIONS FOR TAILORING GRADUATE EDUCATION TO HELP CURRENT AND FUTURE GENERATIONS OF STUDENTS THINK INTERDISCIPLINARILY

The obstacles mentioned above can be overcome by a new generation of scientists trained for interdisciplinary research. Fortunately, interdisciplinary graduate programs already have and are being increasingly developed. However, interdisciplinary education should begin at the undergraduate level well before graduate study. Many disciplines still funnel student effort and study to their major discipline choices. Focused effort may be necessary for accreditation and fulfillment of other requirements, but also ends up fostering students’ preference for and emulation of a unidisciplinary approach in their graduate education. Aspiring graduate students might only search out unidisciplinary options for graduate programs, or only look at the sometimes clearer employment opportunities that exist at the conclusion of unidisciplinary degrees. Their limited experience and exposure is constraining. To help remedy this problem, there needs to be a visible outreach to undergraduates to inform them of the expanded opportunities for employment that accompany both wider undergraduate experiences and interdisciplinary graduate education.

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Interdisciplinary graduate programs that are in existence come in many formats. One model for graduate education is that a department develops a program that provides training across disciplines that would include, in the case of adolescent development and puberty, basic anatomy and physiology of the reproductive system, longitudinal methodology, and biomarker assays. Students are thus prepared to evaluate intraand interindividual dynamic change, and to understand and translate findings from other disciplines (e.g., between animal and human models, from genetic and neuroscience studies). Students in interdisciplinary programs integrate conceptualizations and skills that are taught from each departments' own perspective. Yet other programs require that students work with multiple mentors from multiple disciplines.

Completing an interdisciplinary doctorate in an existing department, school, or group program may not be to a student's advantage because access to space, financial support, and supervision may be much more difficult for interdisciplinary students. One encouraging step is that interdisciplinary departments are developing internal pilot funds for graduate students working with someone outside their department or otherwise incentivizing broader collaborations. A graduate program at Berkeley is illustrative of this new approach (http://grad.berkeley.edu/programs/interdisciplinary/). Graduate students who have successfully completed at least two semesters of graduate study in a doctoral program find five faculties from multiple departments to support work and projects that cannot be completed in one of UC Berkeley's existing graduate programs. The proposal the student writes is judged against existing programs where one might complete the research.

Other interdisciplinary graduate programs are situated outside of traditional departments, requiring coursework and training from faculty in multiple departments, and multiple laboratory rotations. Such programs are in operation, for example, at Purdue University (https://purdue.edu/gradschool/oigp/programs/index.html), University of Texas–Austin (https://gradschool.utexas.edu/academics/programs/interdisciplinary-degree-programs), University of Iowa (https://www.grad.uiowa.edu/programs/interdisciplinary-graduate-programs), and in the form of graduate groups at UC Davis (https://grad.ucdavis.edu/programs/graduate-groups) among many others.

Buss (2003) suggests four primary enticements that interdisciplinary programs can use to their advantage. First, there is widespread public perception that leading science endeavors cross old boundaries. Interdisciplinarity is necessary for progress. Second, there are concrete data and word-of-mouth stories of highly successful students in interdisciplinary programs. Third, interdisciplinary programs often include enticing and interesting courses in their curriculum. Interdisciplinary programs often involve multiple departments with lists of courses that far exceed those in a single department. Fourth, innovative students who are eager to explore several areas of research want to expand their skills into the niches between disciplines. There are many career development awards for students and mid-career and late-career scientists that are designed to protect time to devote to this type of cross-training research (e.g., K-awards). It is clear now that becoming conversant in another related discipline is an excellent step in career development—both for junior and senior scientists. Although collaborative partnerships across disciplines may be slower to arrive at outcomes they will result in increased communication across disciplines and stronger interdisciplinary

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teams. Senior scientists are encouraged to take time to mentor students and early career scientists from other disciplines.

ISSUES RELATED TO PUBLICATION, EDUCATION OF EDITORS, AND SOLICITATION OF RELATED DISCIPLINES

Interdisciplinary collaboration and publishing about puberty in journals outside of development/psychobiology journals is often challenging, in part because of disciplinary differences in methods and analytical approach. Reviewers from disciplines that use experiments and causal models can be disgruntled by observational research in naturalistic settings. The reverse is also true. Social and behavioral scientists can be frustrated by the lack of ecological validity of experiments such as those that look at the effects of administering estrogen and testosterone in clinical trials on behavior, emotions, and cognition in delayed puberty girls and boys (Finkelstein et al., 1997, 1998; Liben et al., 2002; Susman et al., 1998). Thus, it is often difficult to find where interdisciplinary work fits best. Even then, the work must be tailored to the chosen readership. Authors' careful reading of published manuscripts in the journal of choice will help them skillfully describe the research in ways that facilitate interpretation and relevance across disciplines.

There is also the need to develop a consensus across journals, editors, and reviewers for what kinds of data about puberty need to be interdisciplinary; longitudinal, epidemiological, case studies, experimental, and other large and small-scale designs. This consensus should also specify the level of evidence needed to accept patterns of findings across levels of analysis and across disciplines. Of note is that most recent research on pubertal development makes use of nomothetic (between-person) approaches. Funding bodies concerned with addressing societal challenge and transforming the knowledge base, however, are also affirming the need to differentiate within and between-person variance. There are calls for more idiographic approaches that make use of new technology for studying within-person change, for example using ecological momentary assessments (Shiffman, Stone, & Hufford, 2008), smartphones, wearables, and ambulatory assessment of hormones (van Ockenburg, Booij, Riese, Rosmalen, & Janssens, 2015). The advances in analysis of intensive repeated measures and idiographic research paradigms provide new opportunities to bring together a new set of seemingly disparate disciplines, including computer scientists and biochemists, and to add conceptual depth to understanding of individuals' experience of puberty.

Strategic and concerted actions by scientists and research societies can guide funding investments by developing networks and engaging in feedforward systems to guide research agendas. The support of private and government funding agencies can greatly increase the importance and visibility of interdisciplinary work. Investigators who might otherwise hesitate to submit for interdisciplinary research funding will be buoyed up by the potential to enhance a research application that explicitly demands an interdisciplinary team of investigators. Marketing of interdisciplinary research teams can make good use of print, conference proceedings, social media, and government requests for funding to shape the future agenda of puberty research. Funding for interdisciplinary research is now slightly easier to obtain than in the past and is likely to get even easier given that progress in

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interdisciplinary research is evident in first-rate journals. Groups of scientists from different disciplines may be more likely to solve big problems saving economic resources in the process. Strategic funding can leverage a mass of existing data.

CONCLUSIONS

This article addressed different facets of interdisciplinary research. A brief retrospective view of interdisciplinary work on puberty suggested that increased attention be given to government and foundation funding sources to enhance the future of research on puberty. A description of what is hard and what is easy about interdisciplinary research on puberty alerted current and future scientists to challenges and opportunities for interdisciplinary research. We highlighted some of the major advances of interdisciplinary work on puberty, some of the continuing challenges, and made some recommendations for how graduate education might be tailored to train a new generation of interdisciplinary thinkers. Finally, continuing emphasis related to publication, education of others, and solicitation of related disciplines will alert future scientists how to achieve a successful submission. We now conclude with a vision of the future in this era of high tech, big data thinking policy. Table 1 highlights Interdisciplinary advances, future research needs and modes of learning.

Increased scientific efforts to accurately depict the role of puberty across all facets of life are driven by the consolidation of evidence that puberty is a predictor of physical and psychological health in adolescence and throughout the life span (Negriff & Susman, 2011). Early conceptualizations of puberty as simply a process related to reproductive maturation, or the conflation of the physical changes of puberty and sexuality (e.g., Kirby & Ecker, 2009) may have shaped research discourse and efforts. Puberty is no longer equated solely with the development of reproductive capacity but is recognized as a transitional child-to-adult period with opportunities for prevention of current and future problems as well as opportunities to support positive psychosocial and physical development. Our obligation as authors is to introduce to the readership of journals and to disciplines to the importance of the inherently interdisciplinary phenomena of puberty in theoretical and empirical models (Dornan & Woodward, 2015). Studies of phenomena like progression of disease (asthma, neurological disorders), microbiome changes, drug metabolism, and immune function will also benefit from including information about puberty. It is incumbent on researchers to highlight how interdisciplinary research on pubertal development benefits from an interdisciplinary lens, and this necessitates knowledge transfer across disciplinary boundaries to explicitly draw attention to the importance of puberty for well-being across the entire life course.

In future interdisciplinary teams on puberty, scholars will assume more varied forms, with a growing number of disciplines as part of these teams (e.g., engineers, linguistic specialists, computer scientists). New scholars entering the field will have been trained in both biological and behavioral sciences and can make early career advances in the science of puberty. Importantly, teams will be increasingly guided by interdisciplinary theories, hypotheses, analyses, and conclusions. An important question for university administrators and faculty is at what point in interdisciplinary research there is a need for new departments, centers, and administrative structures to make distinct the importance of interdisciplinary

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research. Institutions that have invested pilot funds into formation of interdisciplinary teams are likely more successful in obtaining grants. A case example is the Penn State Social Science Research Institute (SSRI) which has been identifying and supporting creation of interdisciplinary teams and has a record $20 to $1 return on investment. Continued acceptance of interdisciplinary research will be facilitated by making this research relevant to social and research policy. Given the push by government and nongovernmental funders to inform them of the policy implications of our research, it will not be surprising to see both more interdisciplinary policy-relevant research and more policy implications in concluding sections of papers.

The public is not always aware of the policy implications of research on puberty particularly in educational domains. A specific example is the timing of public health interventions. (See Dorn, Hostinar, Susman, & Pervanidou, 2019, in this issue). For instance, the vaccination for the human papilloma virus (HPV) was discovered to be the most effective for preventing cervical cancer if it was initiated prior to or around the time of puberty. At these ages, adolescents are beginning to initiate sexual activity. Linking early sexual activity, HPV, and reproductive cancer and the importance of timely vaccination was a major public health policy advance that sensitized the public to adolescence as a period of high risk for later cancer. Thus, there is no doubt that to progress in interdisciplinary research, there is a need for both policy research and public health advocacy.

In summary, puberty is an inherently interdisciplinary area of inquiry given that puberty entails major biological, psychological, social, and macroenvironmental influences and changes during the transition from childhood to adolescence. There are now excellent examples of success in interdisciplinary puberty research. However, considerable challenges remain, including the complexity of behavior, biology, and biobehavioral patterns across time and individuals. In order to further advance interdisciplinary research, we should become vocal and articulate advocates. The field will flourish by sharing data, using innovative methods, engaging with new data streams, and developing training programs that support interdisciplinary thinking. Institutional support and strategic funding can promote high-quality, truly interdisciplinary research on puberty. In turn, this research will enhance the healthy development of generations of youth.

REFERENCES

Ahn JJ, O'Mahony J, Moshkova M, Hanwell HE, Singh H, Zhang MA,… Banwell B (2015). Puberty in females enhances the risk of an outcome of multiple sclerosis in children and the development of central nervous system autoimmunity in mice. Multiple Sclerosis Journal, 21, 735–748. 10.1177/1352458514551453 [PubMed: 25533291]

Allen AP, Dinan TG, Clarke G, & Cryan JF (2017). A psychology of the human brain–gut–microbiome axis. Social and Personality Psychology Compass, 11, 1–22. 10.1111/spc3.12309

Arbel R, Rodriguez AJ, & Margolin G (2016). Cortisol reactions during family conflict discussions: Influences of wives' and husbands' exposure to family-oforigin aggression. Psychology of Violence, 6, 519–528. 10.1037/a0039715 [PubMed: 28042495]

Aylwin CF, Toro CA, Shirtcliff E, & Lominiczi A (2019). Emerging genetic and epigenetic mechanisms underlying pubertal maturation in adolescence. Journal of Research on Adolescence, 29, 54–79. 10.1111/jora.12385 [PubMed: 30869843]

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Bainter SA, & Curran PJ (2015). Advantages of integrative data analysis for developmental research. Journal of Cognition and Development, 16, 1–10. 10.1080/15248372.2013.871721 [PubMed: 25642149]

Bauer DJ, & Hussong AM (2009). Psychometric approaches for developing commensurate measures across independent studies: Traditional and new models. Psychological Methods, 14, 101 10.1037/a0015583 [PubMed: 19485624]

Belsky J, & Pluess M (2009). Beyond diathesis stress: Differential susceptibility to environmental influences. Psychological Bulletin, 136, 885–908. 10.1037/a0017376

Boyce WT, & Ellis BJ (2005). Biological sensitivity to context: An evolutionary–developmental theory of the origins and functions of stress reactivity. Development and Psychopathology, 17, 271–301. 10.1017/s095457940505014 [PubMed: 16761546]

Braams BR, van Duijvenvoorde AC, Peper JS, & Crone EA (2015). Longitudinal changes in adolescent risk-taking: A comprehensive study of neural responses to rewards, pubertal development, and risktaking behavior. Journal of Neuroscience, 35, 7226–7238. 10.1523/JNEUROSCI.4764-14.2015 [PubMed: 25948271]

Brody GH, Beach SR, Philibert RA, Chen YF, Lei MK, Murry VM, & Brown AC (2009). Parenting moderates a genetic vulnerability factor in longitudinal increases in youths' substance use. Journal of Consulting and Clinical Psychology, 77, 1–11. 10.1111/j.1467-8624.2009.01288.x [PubMed: 19170449]

Brooks-Gunn J, & Peterson AC (Eds.). (1983). Girls at puberty: Biological and psychosocial perspectives. Berlin, Germany: Springer 10.1007/978-1-4899-0354-9

Brooks-Gunn J, & Warren MP (1989). Biological contributions to affective expression in young adolescent girls. Child Development, 60, 372–385. [PubMed: 2924657]

Buss J (2003). Why interdisciplinary graduate programs attract great graduate students. Conference in the Merrill series, The Research Mission of Public Universities Retrieved from dept.ku.edu/~merrill/PDFfiles/buss.pdf

Corley RP, Beltz AM, Wadsworth SJ, & Berenbaum SA (2015). Genetic influences on pubertal development and links to behavior problems. Behavior Genetics, 45, 294–312. 10.1007/s10519-015-9719-5 [PubMed: 25903988]

Cousineau TM, Franko DL, Trant M, Rancourt D, Ainscough J, Chaudhuri A, & Brevard J (2010). Teaching adolescents about changing bodies: Randomized controlled trial of an internet puberty education and body dissatisfaction prevention program. Body Image, 7, 296–300. 10.1016/j.bodyim.2010.06.003 [PubMed: 20638919]

Cousminer DL, Berry DJ, Timpson NJ, Ang W, Thiering E, Byrne EM, & Wid'en E (2013). Genome-wide association and longitudinal analyses reveal genetic loci linking pubertal height growth, pubertal timing and childhood adiposity. Human Molecular Genetics, 22, 2735–2747. 10.1093/hmg/ddt104 [PubMed: 23449627]

Cousminer DL, Stergiakouli E, Berry DJ, Ang W, Groen-Blokhuis MM, Korner A, & Wid'en E (2014). Genome-wide association study of sexual maturation in males and females highlights a role for body mass and menarche loci in male puberty. Human Molecular Genetics, 23, 4452–4464. 10.1093/hmg/ddu150 [PubMed: 24770850]

Cousminer DL, Wid'en E, & Palmert MR (2016). The genetics of pubertal timing in the general population: Recent advances and evidence for sex-specificity. Current Opinion in Endocrinology and Diabetes and Obesity, 23, 57–65. 10.1093/hmg/ddt104

Day FR, Thompson DJ, Helgason H, Chasman DI, Finucane H, Sulem P,… Perry JRB (2017). Genomic analyses identify hundreds of variants associated with age at menarche and support a role for puberty timing in cancer risk. Nature Genetics, 49, 834–841. 10.1038/ng.3841 [PubMed: 28436984]

Day J, Savani S, Krempley BD, Nguyen M, & Kitlinska JB (2016). Influence of paternal preconception exposures on their offspring: Through epigenetics to phenotype. American Journal of Stem Cells, 5, 11–18. [PubMed: 27335698]

Dobbins C, Merabti M, Fergus P, & Llewellyn-Jones D (2012). Augmenting human digital memories with physiological data. In 2012 IEEE 3rd international conference on networked embedded systems for every application (NESEA) (pp. 1–7). 10.1109/nesea.2012.6474032

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Dorn LD, & Biro FM (2011). Puberty and its measurement: A decade in review. Journal of Research on Adolescence, 21, 180–195. 10.1111/j.1532-7795.2010.00722.x

Dorn LD, Dahl R, Woodward HR, & Biro F (2006). Defining the boundaries of early adolescence: A user's guide to assessing pubertal status and pubertal timing in research with adolescents. Applied Developmental Science, 10, 30–56. 10.1207/s1532480xads1001_3

Dorn LD, Hostinar C, Susman EJ, & Pervanidou P (2019). Conceptualizing puberty as a window of opportunity for impacting health and wellbeing across the lifespan. Journal of Research on Adolescence, 29, 155–176. 10.1111/jora.12431 [PubMed: 30869846]

Dornan P, & Woodward M (2015). How inequities develop through childhood: Life course evidence from the Young Lives Cohort Study. UNICEF Retrieved from https://www.unicef-irc.org/publications/769/

Dulka EA, & Moenter SM (2017). Prepubertal development of gonadotropin-releasing hormone neuron activity is altered by sex, age, and prenatal androgen exposure. Endocrinology, 58, 3943–3953. 10.1210/en.2017-00768

Dungan HM, Clifton DK, & Steiner RA (2006). Minireview: Kisspeptin neurons as central processors in the regulation of gonadotropin-releasing hormone secretion. Endocrinology, 147, 1154–1158. 10.1210/en.2005-1282 [PubMed: 16373418]

Elks CE, Perry JR, Sulem P, Chasman DI, Franceschini N, He C, & Cousminer DL (2010). Thirty new loci for age at menarche identified by a meta-analysis of genome-wide association studies. Nature Genetics, 42, 1077–1085. 10.1038/ng.714 [PubMed: 21102462]

Ellis BJ, Boyce WT, Belsky J, Bakermans-Kranenburg MJ, & van Ijzendoorn MH (2011). Differential susceptibility to the environment: An evolutionary–neurodevelopmental theory. Development and Psychopathology, 23, 7–28. https://doi.org/0.1017/S0954579410000611 [PubMed: 21262036]

Ellis BJ, Shirtcliff EA, Boyce WT, Deardorff J, & Essex MJ (2011). Quality of early family relationships and the timing and tempo of puberty: Effects depend on biological sensitivity to context. Development and Psychopathology, 23, 85–99. 10.1017/S0954579410000660 [PubMed: 21262041]

Fernandez-Rhodes L, Demerath EW, Cousminer DL, Tao R, Dreyfus JG, Esko T,… Franceschini N (2013). Association of adiposity genetic variants with menarche timing in 92,105 women of European descent. Genet, 45, 294–312. 10.1007/s10519-015-9719-5

Finkelstein JW, Susman EJ, Chinchilli VM, Kunselman SJ, D'Arcangelo MR, Schwab J,… Kulin HE (1997). Estrogen or testosterone increases selfreported aggressive behaviors in hypogonadal adolescents. Journal of Clinical Endocrinology and Metabolism, 82, 2423–2438. 10.1210/jcem.82.8.4165 [PubMed: 9253311]

Finkelstein JW, Susman EJ, D'Arcangelo MR, Kunselman SJ, Schwab J, Demers LM,… Kulin HA (1998). Effects of estrogen or testosterone on selfreported sexual responses and behaviors in hypogonadal adolescents. Journal of Clinical Endocrinology and Metabolism, 83, 2281–2285. 10.1210/jcem.83.7.4961 [PubMed: 9661595]

Freud A (1966). The ego and the mechanisms of defense: The writings of Anna Freud. (Rev. ed.) New York, NY: International Universities Press.

Gajdos ZK, Henderson KD, Hirschhorn JN, & Palmert MR (2010). Genetic determinants of pubertal timing in the general population. Molecular and Cellular Endocrinology, 324, 21–29. 10.1016/j.mce.2010.01.038 [PubMed: 20144687]

Ge X, Natsuaki MN, Neiderhiser JM, & Reiss D (2007). Genetic and environmental influences on pubertal timing: Results from two national sibling studies. Journal of Research on Adolescence, 17, 767–788. 10.1007/s10964-012-9762-y

Goddings AL, Beltz A, Peper J, Crone E, & Braams B (2019). Understanding the role of puberty in structure and functional development of the adolescent brain. Journal of Research on Adolescence, 29, 32–53. 10.1111/jora.12408 [PubMed: 30869842]

Gordis EB, Margolin G, Spies LA, & Susman EJ (2010). Interparental aggression and parent–adolescent salivary alpha amylase symmetry. Physiology and Behavior, 100, 225–233. 10.1016/j.physbeh.2010.01.006 [PubMed: 20096715]

Gosling SD (2001). From mice to men: What can we learn about personality from animal research? Psychological Bulletin, 127, 45–86. 10.1037/0033-2909.127.1.45 [PubMed: 11271756]

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Grimm KJ, Ram N, & Hamagami F (2011). Nonlinear growth curves in developmental research. Child Development, 82, 1357–1371. 10.1111/j.1467-8624.2011.01630.x [PubMed: 21824131]

Grumbach MM, & Styne DM (1998). Puberty: Ontogeny, neuroendocrinology, physiology, and disorders In Wilson F & Kronenberg F (Eds.), Williams textbook of endocrinology (9th ed., pp. 1573–1623). Philadelphia, PA: Saunders.

Gunnar MR, Wewerka S, Frenn K, Long JD, & Griggs C (2009). Developmental changes in hypothalamus–pituitary–adrenal activity over the transition to adolescence: Normative changes and associations with puberty. Development and Psychopathology, 21, 69–85. 10.1017/S0954579409000054 [PubMed: 19144223]

Gur RE, & Gur RC (2016). Sex differences in brain and behavior in adolescence: Findings from the Philadelphia Neurodevelopmental Cohort. Neuroscience and Biobehavioral Reviews, 70, 159–170. 10.1016/j.neubiorev.2016.07.035 [PubMed: 27498084]

Halpern CJT, Udry JR, & Suchindrand C (2000). Monthly measures of salivary testosterone predict sexual activity in adolescent males. Journal of Sex Research, 27, 445–465.

Han SC, & Margolin G (2016). Intergenerational links in victimization: Prosocial friends as a buffer. Journal of Child and Adolescent Trauma, 9, 156–165. 10.1007/s40653-015-0075-7

Hofer SM, & Piccinin AM (2009). Integrative data analysis through coordination of measurement and analysis protocol across independent longitudinal studies. Psychological Methods, 14, 150–164. 10.1037/a0015566 [PubMed: 19485626]

Huang B, Hillman J, Ding L, Biro FM, Dorn LD, & Susman EJ (2012). Correspondence between gonadal steroid hormone concentrations and secondary sexual characteristics assessed by clinicians, adolescents, and parents. Journal of Research on Adolescence, 2292, 381–391. 10.1111/j.1532-7795.2011.00773.x

Kipke MD (1999). Adolescent development and the biology of puberty: Summary of a workshop on new research. Washington, DC: National Academies Press.

Kirby D, & Ecker N (2009). International technical guidance on sexuality education: An evidence-informed approach for schools, teachers and health educators. Paris, France: United Nations Educational, Scientific and Cultural Organization.

Klein JT (1990). Interdisciplinarity: History, theory and practice. Detroit, MI: Wayne State University Press.

Knopik VS (2009). Maternal smoking during pregnancy and child outcomes: Real or spurious effect? Developmental Neuropsychology, 34, 1–36. 10.1080/87565640802564366 [PubMed: 19142764]

Lerner RM, Almerigi JB, Theokas C, & Lerner J (2005). Positive youth development a view of the issues. Journal of Early Adolescence, 25, 10–16. 10.1177/0272431604273211

Li H, Ji C, Yang L, & Zhuang C (2016). Heritability of serum dehydroepiandrosterone sulphate levels and pubertal development in 6 approximately 18year-old girls: A twin study. Annals of Human Biology, 1–7, 10.1080/03014460.2016.1240232

Liben LS, Susman EJ, Krogh HR, Chinchilli VM, Kunselman S, D'Arcangelo R,… Kulin HE (2002). The effects of sex steroids on spatial cognition during induced puberty. Developmental Psychology, 38, 236–253. 10.1037/0012-1649.38.2.236 [PubMed: 11881759]

Lomniczi A, Loche A, Castellano JM, Ronnekleiv OK, Bosch M, Kaidar G, & Ojeda SR (2013). Epigenetic control of female puberty. Nature Neuroscience, 16, 281–289. 10.1038/nn.3319 [PubMed: 23354331]

Lomniczi A, Wright H, & Ojeda SR (2015). Epigenetic regulation of female puberty. Frontiers in Neuroendocrinology, 36, 90–107. 10.1016/j.yfrne.2014.08.003 [PubMed: 25171849]

Manfredi-Lozano M, Roa J, Ruiz-Pino F, Piet R, Garcia-Galiano D, Pineda R,… Dieguez C (2016). Defining a novel leptin–melanocortin–kisspeptin pathway. Molecular Metabolism, 5, 844–857. 10.1016/j.molmet.2016.08.003 [PubMed: 27688998]

Marceau K, Ram N, Houts RM, Grimm KJ, & Susman EJ (2011). Individual differences in boys' and girls' timing and tempo of puberty: Modeling development with nonlinear growth models. Developmental Psychology, 47, 1389 10.1037/a0023838 [PubMed: 21639623]

Margolin G, Ramos MC, Timmons AC, Miller KF, & Han SC (2016). Intergenerational transmission of aggression: Physiological regulatory processes. Child Development Perspectives, 10, 15–21. 10.1111/cdep.12156 [PubMed: 26929773]

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Margolin G, Spies LA, & Baucom B (2012). Does dampened physiology reactivity protect youth in aggressive family environments? Child Development, 83, 821–830. 10.1111/j.1467-8624.2012.01752.x [PubMed: 22548351]

Marshall WA, & Tanner JM (1969). Variations in patterns of pubertal change in girls. Archives of Disease in Childhood, 44, 291–303. https://doi.org/1136/adc.44.235.29 [PubMed: 5785179]

Marshall WA, & Tanner JM (1970). Variations in the pattern of pubertal change in boys. Archives of Disease in Childhood, 45, 13–23. 10.1136/adc.45.239.13 [PubMed: 5440182]

Matchock RL, Dorn LD, & Susman EJ (2007). Circadian and circannual cortisol, testosterone, and DHEA rhythms in boys and girls: Relationship to pubertal stage. Chronobiology International, 24, 969–990. 10.1080/07420520701649471 [PubMed: 17994350]

Mendle J, Beltz A, Carter R, & Dorn LD (2019). Understanding puberty and its measurement: Ideas for research in a new generation of youth. Journal of Research on Adolescence, 29, 82–95. 10.1111/jora.12371 [PubMed: 30869839]

Mendle J, Turkheimer E, D'Onofrio BM, Lynch SK, Emery RE, Slutske WS, & Martin NG (2006). Family structure and age at menarche: A children-oftwins approach. Developmental Psychology, 42, 533–542. 10.1037/0012-1649.42.3.533 [PubMed: 16756443]

Miocevic O, Cole CR, Laughlin MJ, Buck RL, Slowey PD, & Shirtcliff EA (2016). Technology for rapid assessment of salivary cortisol demonstrates as reliable alternative to traditional immunoassays. Psychoneuroendocrinology, 71, 67 10.1016/j.psyneuen.2016.07.174

National Longitudinal Study of Adolescent Health. (2017). Retrieved from https://www.icpsr.umich.edu/icpsrweb/DSDR/studies/21600

Negriff S, & Susman EJ (2011). Pubertal timing, depression, and externalizing problems: A framework, review, and examination of gender differences. Journal of Research on Adolescence, 21, 717–746. 10.1111/j.1532-7795.2010.00708.x

Neufeld KAM, Luczynski P, Oriach CS, Dinan TG, & Cryan JF (2016). What's bugging your teen? The microbiota and adolescent mental health. Neuroscience and Biobehavioral Reviews, 70, 300–312. 10.1016/j.neubiorev.2016.06.005. [PubMed: 27287940]

Nye A (2015). Socrates and Diotima: Sexuality, religion, and the nature of divinity. New York, NY: Palgrave MacMillian 10.1057/9781137514042

van Ockenburg SL, Booij SH, Riese H, Rosmalen JG, & Janssens KA (2015). How to assess stress biomarkers for idiographic research. Psychoneuroendocrinology, 62, 189–199. 10.1016/j.psyneuen.2015.08.002 [PubMed: 26318629]

Ojeda SR, Dubay C, Lomniczi A, Kaidar G, Matagne V, Sandau US, & Dissen GA (2010). Gene networks and the neuroendocrine regulation of puberty. Molecular and Cellular Endocrinology, 324, 3–11. 10.1016/j.mce.2009.12.003 [PubMed: 20005919]

Ojeda SR, & Lomniczi A (2014). Puberty in 2013: Unravelling the mystery of puberty. Nature Reviews Endocrinology, 10, 67–69. 10.1038/nrendo.2013.233

Ojeda SR, & Terasawa E (2002). Neuroendocrine regulation of puberty In Pfaff D, Arnold A, Etgen A, Fahrbach S, Moss R & Rubin R (Eds.), Hormones, brain and behavior (Vol 4, pp. 589–659). New York, NY: Elsevier 10.1016/B978-012532104-4/50077-9

Ong KK, Elks CE, Wills AK, Wong A, Wareham NJ, Loos RJ, & Hardy R (2011). Associations between the pubertal timing-related variant in LIN28B and BMI vary across the life course. Journal of Clinical Endocrinology and Metabolism, 96, E125–E129. 10.1210/jc.2010-0941 [PubMed: 20962026]

van Panhuis WG, Paul P, Emerson C, Grefenstette J, Wilder R, Herbst AJ,… Burke DS (2014). A systematic review of barriers to data sharing in public health. BMC Public Health, 14, 1144 10.1186/1471-2458-14-1144 [PubMed: 25377061]

Peeters F, Nicolson NA, & Berkhof J (2004). Levels and variability of daily life cortisol secretion in major depression. Psychiatry Research, 126, 1–13. 10.1016/j.psychres.2003.12.010 [PubMed: 15081622]

Peper JS, & Dahl RE (2013). The teenage brain: Surging hormones–Brain behavior interactions during puberty. Current Directions in Psychological Science, 22, 134–139. 10.1177/096372141247.3755 [PubMed: 26290625]

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Perry JR, Day F, Elks CE, Sulem P, Thompson DJ, Ferreira T,… Albrecht E (2014). Parent-of-origin specific allelic associations among 106 genomic loci for age at menarche. Nature, 514, 92 10.1038/nature13545 [PubMed: 25231870]

Petersen AC, & Leffert N (1995). Developmental issues influencing guidelines for adolescent health research: A review. Journal of Adolescent Health, 17, 298–305. 10.1016/1054-139X(95)00184-T [PubMed: 8924434]

Plant TM, & Dubey AK (1984). Evidence from the rhesus monkey (Macaco mulatto) for the view that negative feedback control of luteinizing hormone secretion by the testis is mediated by a deceleration of hypothalamic gonadotropin-releasing hormone pulse frequency. Endocrinology, 115, 2145–2153. 10.1210/endo-115-6-2145 [PubMed: 6437793]

Plant TM, & Ramaswam S (2009). Kisspeptin and the regulation of the hypothalamic–pituitary–gonadal axis in the rhesus monkey (Macaca mulatta). Peptides, 30, 67–75. 10.1016/j.peptides.2008.06.029 [PubMed: 18662732]

Plant TM, Rast TM, Gay VL, Marshall GR, & Arslan M (1989). Puberty in monkeys is triggered by chemical stimulation of the hypothalamus. Proceedings of the National Academy of Sciences, 86, 2506–2510. 10.1073/pnas.86.7.2506

Plant TM, & Shahab M (2002). Neuroendocrine mechanisms that delay and initiate puberty in higher primates. Physiology and Behavior, 77, 717–722. 10.1016/s0031-9384(02)00924-1 [PubMed: 12527025]

Poline JB, Breeze JL, Ghosh S, Gorgolewski K, Halchenko YO, Hanke M, … Kennedy DN (2012). Data sharing in neuroimaging research. Frontiers Neuroinformatics, 5, 6–9. 10.3389/fninf.2012.00009

Ram N, & Gerstorf D (2009). Time-structured and net intraindividual variability: Tools for examining the development of dynamic characteristics and processes. Psychology and Aging, 24, 778–791. 10.1037/a0017915 [PubMed: 20025395]

Robinson H (2003). Dualism In Stich S & Warfield T (Eds.), The Blackwell guide to philosophy of mind (pp. 85–101). Oxford,UK: Blackwell.

Rogol AD, Clark PA, & Roemmich JN (2000). Growth and pubertal development in children and adolescents: Effects of diet and physical activity. American Journal of Clinical Nutrition, 72, S521S–S528S. 10.1093/ajcn/72.2.521S

Roth CL, Mastronardi C, Lomniczi A, Wright H, Cabrera R, Mungenast AE, & Ojeda SR (2007). Expression of a tumor-related gene network increases in the mammalian hypothalamus at the time of female puberty. Endocrinology, 148, 5147–5161. 10.1210/en.2007-0634 [PubMed: 17615149]

Sameroff AJ, & Suomi S (1996). Primates and persons: A comparative developmental understanding of social organization In Cairns R, Elser H, & Costello G (Eds.), Developmental Science (pp. 97–120). New York, NY: Cambridge University Press.

Saxby D, Del Piero LB, Borofsky L, ImmordinoYang MH, Kaplan JT, & Margolin G (2016). Neural mediators of the intergenerational transmission of family aggression. Development and Psychopathology, 58, 595–606. 10.1017/S0954579415000528

Saxby DE, Margolin G, Spies Shapiro LA, & Baucom BR (2018). Does dampened physiological reactivity protect youth in aggressive family environments. Child Development, 83, 821–830. 10.1111/j.1467-8624.2012.01752.x

Schulz KM, & Sisk CL (2016). The organizing actions of adolescent gonadal steroid hormones on brain and behavioral development. Neuroscience and Biobehavioral Reviews, 70, 148–158. 10.1016/j.neubiorev.2016.07.036 [PubMed: 27497718]

Selye H (1973). The evolution of the stress concept. American Scientist, 61, 692–699. [PubMed: 4746051]

Shiffman S, Stone AA, & Hufford MR (2008). Ecological momentary assessment. Annual Review of Clinical Psychology, 4, 1–32. 10.1146/annurev.clinpsy.3.022806.091415

Shirtcliff E, & Essex M (2008). Concurrent and longitudinal associations of basal and diurnal cortisol with mental health symptoms in early adolescence. Developmental Psychobiology, 50, 690–703. 10.1002/dev.20336 [PubMed: 18726897]

Si J, Barto WP, & Donald W (Eds.). (2004). Learning and approximate dynamic programming: Scaling up to the real world. New York, NY: Wiley 10.1109/9780470544785

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Silventoinen K, Haukka J, Dunkel L, Tynelius P, & Rasmussen F (2008). Genetics of pubertal timing and its associations with relative weight in childhood and adult height: The Swedish Young Male Twins Study. Pediatrics, 121, e885–e891. 10.1542/peds.2007-1615 [PubMed: 18381517]

Sisk CL (2017). Development: Pubertal hormones meet the adolescent brain. Current Biology, 27, R706–R708. 10.1016/j.cub.2017.05.092 [PubMed: 28743017]

Spear LP (2011). Rewards, aversions and affect in adolescence: Emerging convergences across laboratory animal and human data. Developmental Cognitive Neuroscience, 1, 390–403. 10.1016/j.dcn.2011.08.001

Spear LP, & Silveri MM (2016). Special issue on the adolescent brain. Neuroscience and Biobehavioral Reviews, 70, 1–3. 10.1016/j.neubiorev.2016.08.004 [PubMed: 27497719]

Spies LA, Margolin G, Susman EJ, & Gordis EB (2011). Adolescents' cortisol reactivity and subjective distress in response to family conflict: The moderating role of internalizing symptoms. Journal of Adolescent Health, 49, 386–392. 10.1016/j.jadohealth.2011.01.014 [PubMed: 21939869]

Stroud LR, Papandonatos GD, Williamson DE, & Dahl RE (2004). Sex differences in the effects of pubertal development on responses to a corticotropinreleasing hormone challenge: The Pittsburgh psychobiologic studies. Annals of the New York Academy of Sciences, 1021, 348–351. 10.1016/j.psyneuen.2011.02.017 [PubMed: 15251908]

Suleiman AB, Galv'an A, Harden KP, & Dahl RE (2017). Becoming a sexual being: The "elephant in the room" of adolescent brain development. Developmental Cognitive Neuroscience, 25, 209–220. 10.1016/j.dcn.2016.09.004 [PubMed: 27720399]

Susman EJ, Dockray S, Schiefelbein VL, Heaton JA, Herwehe S, & Dorn LD (2007). Morningness/eveningness, morning to afternoon cortisol ratio and antisocial behavior problems during puberty. Developmental Psychology, 43, 811–822. 10.1037/0012-1649.43.4.811 [PubMed: 17605516]

Susman EJ, Dorn LD, Inoff-Germain G, Nottelmann ED, & Chrousos GP (1997). Cortisol reactivity, distress behavior, behavior problems, and emotionality in young adolescents: A longitudinal perspective. Journal of Research on Adolescence, 7, 81–105. 10.1207/s15327795jra0701_5

Susman EJ, Finkelstein JW, Chinchilli VM, Schwab J, Liben LS, D'Arcangelo MR,… Kulin HE (1998). The effect of sex hormone replacement therapy on behavior problems and moods in adolescents with delayed puberty. Journal of Pediatrics, 33, 521–525. 10.1210/jcem.82.8.4165

Susman EJ, Houts RM, Steinberg Belsky LJ, Cuffman E, DeHart G, Friedman SL,… The NICHD Early Child Care Research Networks. (2010). Longitudinal development of secondary sexual characteristics in girls and boys between ages 9½ and 15½ years. Archives of Pediatrics and Adolescent Medicine, 164, 166–173. 10.1001/archpediatrics.2009.261 [PubMed: 20124146]

Susman EJ, Inoff-Germain GE, Nottelmann ED, Cutler GB, Loriaux DL, & Chrousos GP (1987). Hormones, emotional dispositions and aggressive attributes in young adolescents. Child Development, 58, 1114–1134. 10.2307/1130551 [PubMed: 3608660]

Tan LJ, Wang ZE, Wu KH, Chen XD, Zhu H, Lu S,… Deng HW (2015). Bivariate genome-wide association study implicates ATP6V1G1 as a novel pleiotropic locus underlying osteoporosis and age at menarche. Journal of Clinical Endocrinology Metabolism, 100, E1457–E1466. 10.1210/jc.2015-2095 [PubMed: 26312577]

Tenopir C, Dalton ED, Allard S, Frame M, Pjesivac I, Birch B,… Dorsett K (2015). Changes in data sharing and data reuse practices and perceptions among scientists worldwide. PLoS ONE, 10, e0134826 10.1371/journal.pone.0134826 [PubMed: 26308551]

Tu W, Wagner EK, Eckert GJ, Yu Z, Hannon T, Pratt JH, & He C (2015). Associations between menarche-related genetic variants and pubertal growth in male and female adolescents. Journal of Adolescent Health, 56, 66–72. 10.1016/j.jadohealth.2014.07.02 [PubMed: 25287989]

van den Berg SM, Setiawan A, Bartels M, Polderman TJ, van der Vaart AW, & Boomsma DI (2006). Individual differences in puberty onset in girls: Bayesian estimation of heritabilities and genetic correlations. Behavior Genetics, 36, r261 10.1007/s10519-005-9022-y

Vierimaa M, Bruner MW, & Côté J (2018). Positive youth development and observed athlete behavior in recreational sport. PLoS ONE, 01, e0191936.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Wartella E, Rideout V, Montague H, Beaudoin-Ryan L, & Lauricella A (2016). Teens, health and technology: A national survey. Media and Communication, 4, 1–3. http://dx.doi.org.ezaccess.libraries.psu.edu/10.17645/mac.v4i3.515

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Table 1.

Interdisciplinary advances, future research needs and modes of learning

Advances	Future Research Needs	Modes of learning*
Behavioral Sciences	Theories that better integrate aspects of behavior, emotions and cognition and biological systems: • Theories of biobehavioral development • Advanced methodology and statistics • Systems theory	Classes, workshops, web-based seminars and conferences: YouTube conferences, invite interdisciplinary scientists. Online courses, including interactive modes
Genetics	Training that orients scientists to understand: • Basic biology of genetics • Molecular and behavioral genetics • Epigenetics • Mutations • Methylation Discovering whether genetic studies in animals models translate to humans	Introductory and advanced classes that cover the basics of genetics, bioinformatics and integration of genetic theories into behavioral theories of development. Hands on experiences in DNA sequencing, methylation, and epigenetics
Neuroscience	Training scientists and students on basic anatomy and physiology and structure and function, of the brain-nervous system: • Neurotransmitters • Receptors • Methylation	Workshops and online courses Practical lab experience Collaborations with behavior geneticists
Methodology and statistics	Systematic orientation and integration of advanced statistics in research and education to acquaint graduate students and scientists of the potential of advanced statistics	
Adolescent Medicine	Interdisciplinary seminars informing other scientists how adolescent medicine contributes to other scientific domains.	Behavioral science, workshops relevant to the evolving behavior of adolescents.

*Note: All Modes of Learning likely apply to the majority of Future Research Needs.