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School-based sex education and neuroscience: What we know about love, romance, marriage, and adolescent brain development. *Journal of School Health.* (in press).

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ABSTRACT

BACKGROUND

Many school-based abstinence-only sex education curricula state that sexual activity outside of marriage is likely to have harmful psychological effects. Recent advances in neuroscience have expanded our understanding of the neural underpinnings of romantic love, marriage, sexual desire, and sexual behavior and improved our understanding of adolescent brain development.

METHODS

In this article, we review recent advances in neuroscience and clarify what is known about the link between neural development and adolescent romantic and sexual behavior and what opportunities exist for future research.

RESULTS

While the evidence from neuroscience does not yet allow for clear conclusions about the cost or benefits of early romantic relationships and sexual behavior, it does support the idea that providing developmentally appropriate messages that support young people in gaining knowledge and skills that contribute to life-long sexual health.

CONCLUSIONS

Developing policies and practices for school-based sex education that reflects current research will best support the sexual and reproductive health of adolescents throughout their lives.

KEY WORDS: sex education; adolescence; developmental neuroscience; marriage; love

BACKGROUND

Since the 1970's, one of the primary policy responses to address adolescent pregnancy and STI rates, including HIV, has been school-based sex education programs.¹ Today, 33 states and the District of Columbia have policies mandating school-based HIV education, which include information about HIV infection and prevention, while only 22 states and the District of Columbia mandate sex education.¹ Title V of the Social Security Act, Section 510(b) of the Maternal and Child Health Block Services Grant provides the majority of federal funding and policy support for school-based abstinence only sex education.² From the time that Abstinence Education was added to Title V in 1996 through 2007, over 1.5 billion state and federal dollars were allocated to support the development and implementation abstinence-only sex education programs.³ This act requires that youth be taught to abstain from sex until marriage and that besides leading to disease and pregnancy, that “sexual activity outside of the context of marriage is likely to have harmful psychological and physical effects” (510(b)(2)(E)).⁴ This directive persists despite no clear research demonstrating positive social or emotional outcomes of refraining from sex until marriage.² In 2009, acknowledging the limited impact of abstinence-only education on sexual health outcomes, the Consolidated Appropriations Act 2010 renewed a commitment to the federal funding of comprehensive sex education through the Teen Pregnancy Prevention Initiative (TPPI) and the Personal Responsibility and Education Program (PREP).⁵ Despite these new resources available to support the development and implementation of comprehensive sex education programs, significant federal resources continue to support the implementation of abstinence-until-marriage promoting curricula. For example, while the recently released Consolidated and Continuing Appropriations Act of 2015 maintains funding for TPPI and PREP, it also maintains \$5 million in competitive grants for abstinence only funding

and contains a new abstinence only until marriage rider which will provide an additional \$12-15 million per year for abstinence only education.⁶

In an effort to provide evidence of negative psychological effects associated with premarital sex, some abstinence-only researchers and sex education curricula developers have turned towards examining the effects of sexual behavior in the brain.⁷⁻⁹ Recent advances in neuroscience have been influential in expanding our understanding of adolescent sexual behavior. Some of these attempts have led to broad assertions that “modern neuroscience research has uncovered startling new information about how sex affects our brains”⁷ and that developments in neuroscience support the conclusion that “the healthiest behavior, both physically and emotionally, is for persons to abstain from sex until they can commit to one partner for the rest of their lives”.⁷ These claims fail to provide an accurate portrayal of what science has uncovered over the past 20 years in this regard. Broad and unsubstantiated conclusions such as those highlighted above cloud the ways in which advances in neuroscience have expanded our understanding of adolescent sexual and romantic behavior. To inform evidence based policy and practice related to school-based sex education, we must explore what we have learned about adolescent development and how that impacts adolescent romantic and sexual behavior.

The cognitive, hormonal, emotional, and physical changes that accompany the onset of puberty and occur throughout the teenage years play a significant role in aspects of adolescent romantic and sexual decision making. In this article, we review how advances in neuroscience have expanded our understanding of sex, romantic love, marriage, and adolescent brain development. We do this to clarify what is known about the link between neural development and adolescent romantic and sexual behavior to better inform sex education policy and practice.

LITERATURE REVIEW

Romantic Love and Sex

Neuroimaging has helped expand our understanding of the environmental-social-biological interactions related to love and sexual behavior. A number of neuroimaging studies have studied the brain patterns of adults who are in love.¹⁰ A 2012 review, highlights that romantic love activates different brain regions than maternal love, friendship and generalized passion.¹¹ For example, while both romantic love and sexual arousal result in activation of the hypothalamus, maternal love does not.¹⁰ In addition, sexual arousal and desire activate different brain regions than romantic love.¹¹ Brain imaging has also contributed to the understanding that while romantic love activates neural regions associated with emotional processing, love is primarily a goal-oriented motivation, which activates dopamine rich, reward processing systems and motivational systems in the brain.¹² Rather than generating an emotional state, love motivates us to engage in specific behavior. Both romantic feelings and sexual desire are highly context dependent and can occur independently of one another, but additional research is needed to disentangle how distinct love and sexual desire are at a neural level.¹¹ While neuroscience has increased our understanding of the neural correlates of romantic love, how brain activation correlates with romantic behavior is still not well understood.

Desire and motivation. What motivates adolescents to engage in romantic and sexual behavior during and following puberty is a complex interaction of developmental and contextual factors. The interaction between pubertal hormones and brain development play a primary role in this increased motivation. Prior to the collection of any neuroscience data, developmental endocrinology provided some important clues to what motivates early sexual and romantic behavior. The majority of research has focused on the role of testosterone in motivating behavior in both sexes, with more limited research focusing on the role of estrogen. Testosterone has been

generally associated with increased motivation and goal-oriented behavior, which encourages adolescents to try and pursue new things. This hormonally driven increase in motivation can be scaffolded to encourage young people to engage in very positive developmental behaviors—trying out for a new sports team, asking someone out on a date, moving to a new city for college—rather than resulting in more negative health outcomes resulting from risk taking behaviors such as engaging in unprotected sexual intercourse, drinking and driving, or base-jumping from a building.

In general, shifts in gonadal hormones coinciding with puberty have been associated with changes in reward processing – including both increased motivation to seek out rewards and enhanced experience of rewards. In the context of sexual and reproductive health, rewards can range from the good feeling resulting from going out on a date to the physical and emotional experiences associated with sex and intercourse. Testosterone has specifically been implicated in shifts in reward processing which may result in overall increases in reward seeking behavior. While testosterone is normally considered a male hormone, testosterone levels in girls double over the course of puberty with the highest increases observed just before menarche.¹³ In both boys and men and, to a lesser effect in girls and women, higher levels of testosterone have been associated with increased reward-related brain activation.¹⁴ As adolescents experience pubertal increases in testosterone, neuroscience points to the fact that they get a greater reward-response than children or adults, which likely motivates them to continue seeking out reward-generating experiences. Increases in testosterone have also been associated with increased motivation to engage in highly arousing, exciting experiences and a stronger interest in peer relationships.¹⁵ Building on the general relationship between gonadal hormones and motivation, this relationship also influences romantic and sexual motivations in both sexes.

Among adult men, Kraemer et al (1976) found that within participants, increases in testosterone were a consequence, not a predictor, of sexual intercourse, and between participants, found an inverse relationship between frequency of intercourse and testosterone levels.¹⁶ Halpern and colleagues (1998) longitudinally tracked adolescent boys over 3 years and found that between participants, increased levels of salivary testosterone were significantly associated with sexual debut, but did not observe any significant within subject changes in sexual debut based on longitudinal increases in testosterone.¹⁷ Exposing pre-pubertal boys to testosterone, Finkelstein and colleagues (1998) observed an increase in boys touching others and experiencing nocturnal emissions.¹⁸ While limited scope and age of these studies points to the need for additional research to understand the testosterone-sexual behavior link, collectively, these data suggests that higher testosterone levels may predict earlier sexual debut in adolescent boys but may be associated with decreased sexual activity overall. In addition, these data suggests that there may be some threshold effect for testosterone that leads to sexual debut, but no linear relationship between testosterone and subsequent sexual experience.

Testosterone also plays an important role in sexual motivations of female adolescents. Similar to boys, independent of pubertal stage, girls who experience greater increases in testosterone during puberty are more likely to initiate sexual intercourse.¹³ Halpern et al (1997) were able to demonstrate that the association of testosterone on sexual debut could be mediated by frequent attendance at religious services, pointing to the significant environment-behavior-development interaction and the importance of scaffolding as adolescents are experiencing neurohormonal changes.¹³ Additional research focused to identify which environmental factors can most effectively mediate and moderate neurohormonal development is needed to guide interventions aiming to improve adolescent sexual health outcomes. Research focusing on the

relationship between estradiol and sexual motivation has been more limited. One study found that exposing pre-pubertal girls to estrogen resulted in increased kissing and necking behavior compared to non-exposed controls.¹⁸ Similar to boys, for girls, this research suggests that while pubertal hormones, specifically testosterone, are associated with increases in goal-oriented behavior related to sex, but that it does not automatically translate into increased sexual activity.

Love as reward. In addition to being involved in sexual desire, a number of hormones and neurotransmitters are involved in how people experience romantic love including oxytocin, vasopressin, dopamine, serotonin, cortisol, and testosterone.¹⁰ Not coincidentally, many of these hormones and neurotransmitters get activated or enhanced after pubertal maturation is initiated within the adolescent brain. Neuropharmacology studies have helped illustrate the ways in which two important neurohormones, oxytocin and dopamine, interact to facilitate romantic bonding and sexual behavior.¹⁹ These neurohormones are involved in all types of romantic and sexual behavior from pleasant thoughts about a potential partner to holding hands to hugging to sexual intercourse. Brain imaging has helped bolster the claim psychologists have made for years: the dopaminergic reward and goal-directed behavior systems that are hijacked by drugs like cocaine are implicated during romantic love and sexual behavior.²⁰ Despite these similarities, there are important differences in brain activation between drugs and the natural, nondrug reward systems associated with love and sex.²¹ Unlike the dopamine response associated with drug addiction the co-release of oxytocin with dopamine during romantic love and sex, prevents development of tolerance or withdrawal to the burst of neurochemicals.^{22,23} Instead, co-release of oxytocin strengthens the association between oxytocin and dopamine over time, leading to greater and more stable release of these neurotransmitters within the reward system over time as the bond between the individuals is strengthened with each subsequent encounter.²² This co-release helps

create conditioned partner preference, essentially a learned behavior that emerges over time in which that dopaminergic reward is expected and experienced greatest with that bonded partner.^{23,24} As with all learning, this partner preference takes time to develop.

Monogamy and Marriage

Up until 2009, federally funded abstinence-only programs had to teach that “a mutually faithful monogamous relationship in the context of marriage is the expected standard of human sexual activity” and that sexual behavior outside this context is likely to have harmful psychological and physical effects.²⁵ Given that current federal mandates require that abstinence-only education is medically-accurate and evidence-based, it is helpful to explore what we know about the neural underpinnings of sex in the context monogamy and marriage. At this time, we are not aware of any human studies that have determined the neural effects of sex outside the context of marriage. As such, we have turned to the animal literature to explore what has been learned about sex outside the context of monogamy. Because animals do not marry, the research has focused on the concept of monogamous pair bonding.²⁶ Less than 5% of the mammalian population is identified as monogamous.²⁷ and significant debate still exists about whether humans are monogamists, serial monogamists, or poly-amorous by nature.²⁸ In all likelihood, humans may fall into any of these categories, influenced by variability in biological, environmental, and social factors.

Neuroimaging in prairie voles has highlighted that similar to love and sex, the primary neural circuits involved in monogamous pair-bonding are those related to the processing of rewards and social interactions.²⁹ The research on prairie voles has also found that, similar to sex and love, dopamine, oxytocin and vasopressin are involved in establishing long-term pair bonds.²⁹ In areas of the brain associated with pair-bonding behavior, monogamous and non-

monogamous voles have distinct differences in density and distribution of receptors for these hormones.²⁹ Primate research has furthered our understanding of monogamous bonding and demonstrated a great deal of individual variability in activation in regions of the brain associated with reward processing, emotional processing and bonding behavior as they develop new pair bonds.²⁶ Not only do male primates who engage in pair bonding have increased activation in these brain regions compared to male primates who do not bond, but within participants, pair bonding leads to increases in activation in these same regions.²⁶ This suggests that the process of engaging in pair bonding results in changes in neural processing. In addition to differences in neural activity, there are differences in the behaviors of the primates who engage in bonding. While some primates engage quickly in coupling behavior, others take much longer.²⁶ Both data from prairie vole and primate studies points to the fact that the neurocircuitry and behaviors of pair bonding leading to monogamy takes time and that both differ across individuals. From our understanding of adolescent development, we know that adolescents' brains mature, testosterone increases their feelings of desire and oxytocin increases their feelings of love and connection which can lead to longer, more stable romantic relationships.²³ In translating this learning to monogamous bonding behavior in humans, given the increased complexity of human neurosystems and human behavior, our best prediction is that pair bonding is even more flexible, time-consuming, and context dependent than it is for other animals.

While animal research points to some intriguing ways of thinking about long-term monogamous relationships and marriage, we are not aware of any neuroimaging studies that are able to demonstrate specific neural correlates associated with marriage – a social and legal construction. Unlike the studies exploring love mentioned above which have identified distinct neural correlates between romantic love and other types of love, there have not been distinct

neural correlates identified distinguishing married love from non-married love. Furthermore, marriage does not always equate to lifelong romantic bonding and love, as evidenced by prevalence of divorce (50%)³⁰ and infidelity in marriages (approximately 25%).³¹ Poor quality marriages can also have very negative outcomes including poor health outcomes,^{32,33} domestic abuse and jealousy, crimes of passion, and rejection. Instead, the quality of relationship, not marital status, is best predictor of health and relationship satisfaction.³⁴

Adolescent Brain Development

In order to understand how adolescent brain development interacts with sexual desire, sexual behavior and love, it is important to review how adolescent neural development creates intersects with sexual behavior. While puberty launches the neurobehavioral cascade that results in adolescents reaching adult levels of competence in a range of areas, the primary goal of puberty is behavioral and physical sexual and reproductive maturity. Adolescence begins with the hormonal and physiological changes associated with puberty and ends with a social transition to adulthood. The hormonal shifts at the onset of puberty affect brain and body maturation and activate changes in emotions, goals, and motivations.³⁵ Diverse studies have demonstrated that pubertal hormones influence structural brain development and brain function.³⁶ A number of pubertal endocrine factors including testosterone, estrogen, progesterone, prolactin, oxytocin, and cortisol have been demonstrated to be associated with increased sensation seeking, risk taking, and sexual behavior during adolescence.³⁷ A wide range of individual differences, that are not yet well understood, occur within the human genes that regulate these hormones.

Recent developments in neuroscience have highlighted that the interactions between the maturation of cognitive, affective, and social processing during adolescence play a role in understanding adolescent behavior in general and romantic and sexual behavior specifically.³⁵

Adolescence is a period of significant neural plasticity, a process through which thinking and learning transform the brain's physical structure and functional organization.³⁸ As a result of significant developmental changes, adolescents experience new attractions, motivations, and desires for novel experiences. The developmental goal of the interaction between these complex circuits regulating these motivations and desires is not to create a brain that must resist the sexual desires associated with puberty, but rather to gain knowledge, experience, and social-emotional feedback to positively shape these systems. Successful development of these systems allows adolescents not only to inhibit sexual desires, but instead to strategically and methodologically target them in a way to support their personal goals of bonding and/or mating throughout their adult lives.

Cognitive control. During adolescence, both the structure and function of the brain changes. The prefrontal region of the brain, primarily associated with the ability to control one's thoughts and actions, undergoes significant maturation during adolescence.^{33,35} This increased cognitive control capacity allows adolescents to make more adult-like decisions, although this can be highly context dependent. By mid-adolescence, young people have similar cognitive capacities as do adults, as measured in laboratory tests, and understand the range of health and psychosocial risks associated with sexual activity, but they lack specific experience in affective evaluation and regulation related to sex, sexuality, and sexual behavior to employ when making decisions.⁴⁰ While adolescents demonstrate similar cognitive capacity to adults, research has shown that specifically in affectively charged contexts, adolescents take greater risks than adults due to the interaction of cognitive control with social and emotional processing systems.^{41,42} Adolescents' increased cognitive capacity in affectively neutral contexts results from the fact that they have adult-like brain structures but the difference in their behavior likely results from the

fact that adolescents differentially recruit these structurally similar, mature cognitive control regions.⁴³ While the structural components of cognitive control appear earlier in development, the ability to monitor and correct for behavior that results negative outcomes continues to mature well into adulthood.⁴³

Differential activation of key cognitive control regions has been linked to increased impulsivity in general and specifically to increased sexual risk taking. Goldenberg et al (2013) explored the link between cognitive control and sexual behavior in adolescence. When completing an impulse control task in the laboratory, adolescents who took greater sexual risks by using less reliable contraception during intercourse were less likely to recruit relevant prefrontal regions than less risk inclined peers.⁴⁵ Because few other studies have explored this brain development–sexual behavior link it is unclear if the diminished prefrontal activation among adolescents who engage in greater sexual risk taking suggests individual differences independent of or resulting from developmental stage of the brain.⁴⁵ Additional research is needed to explore both possibilities.

The implications for adolescent sexual and romantic behavior are that while adolescents have structurally and functionally similar cognitive control to adults, they may not be able to engage them as effectively or efficiently when faced with highly emotionally charged, novel decisions – the context for the majority of adolescent sexual and romantic decisions. While at face value the limits in cognitive control occurring during adolescence may be a hindrance, in fact, they play an important developmental role in encouraging adolescents to engage in and learn from new experiences important to facilitate the transition into adulthood.

Social-emotional development. During adolescence, young people experience a significant shift in their social behavior – engaging in new types of social relationships and

navigating existing relationships in new ways. This change in behavior is accompanied by changes in neural structure and function.⁴⁶ In addition to increased cognitive control, adolescents experience changes in brain systems involved in understanding and navigating social situations and experiencing empathy, social acceptance, and social rejection.³⁵ These brain systems contribute to the development of social skills and capacities, specifically related to one's ability to engage in pro-social behavior.⁴⁷ Developmentally, pro-social behavior holds great importance as adolescents grapple with engaging in romantic relationships and negotiating sexual limits. Being able to master pro-social behavior influences adolescents' success in romantic relationships, mating, and future sexual behavior throughout their life course.

The neural development linked to emotional processing also highly influences adolescent behavior. Adolescents, despite their increasing self-control, are highly motivated to find novel, exciting, and sensual experiences.⁴⁸ Brain maturation related to affective processing and regulation contributes to increased reward-seeking and sensation-seeking behavior in adolescents.⁴⁸ As a highly affective, inherently social experience with significant potential consequences, romantic and sexual decision making and behavior relies on the complex involvement of these plastic, developing brain systems.

Collectively, our understanding of adolescent brain development points to the fact that adolescents have different neural structures than children and recruit these structures differently than adults. Adolescents' tendency towards enhanced sensation and reward seeking coupled with a diminished capacity to engage their impulse control systems in highly emotionally charged contexts, especially in the presence of peers, often results in increased risk taking. While this increased risk taking serves an important purpose in encouraging adolescents to take new chances, learn new skills, and develop into independent adults, it can also result in a number of

poor sexual health outcomes. Supporting healthy life-long sexual development among adolescents requires going beyond learning to control sexual impulses and instead requires creative interventions that support young people in navigating sexual and romantic motivations and emotions.

IMPLICATIONS FOR SCHOOL HEALTH

Despite some gaps and limitations, existing neuroscience research about sex and romantic love point to some promising directions for future research to better understand adolescent romantic and sexual behavior and inform sex education efforts. This article summarizes the medically accurate, evidence-based available neuroscience literature that can be used to inform school-based sex education. Neuroscience has helped us significantly increase our understanding of adolescent development, love, sex, and pair bonding. First, the neural development associated with puberty leads to increased sensation seeking and risk-taking behavior. Coupled with the physiological sexual maturation of puberty, this results in increased interest in romantic and sexual behavior. Rather than ignoring this interest in highly affectively charged, sensual experiences, sex education must help adolescents learn to direct these desires in positive ways to facilitate their capacity to engage in the intense bonding of a long-term relationship. This behavior is a normal, natural part of adolescent development, which can be influenced by a range of social and environmental factors.

Second, the neural bonds associated with love and sexual behaviors are powerful, unique, and take time to form. The intense desire phase involved in early romantic relationships is necessary to facilitate the internal motivation to develop a long-term pair bond. Just as prairie voles go through a learning process that leads to long-term bonding behavior, the ways in which adolescents learn from early romantic and sexual relationships also contributes to their capacities

in future relationships. The neural and hormonal development occurring through adolescence, accompanied by learning from experience, leads to shifts in roles, desires and motivations that may better prepare individuals for long-term bonding with a mate. At this time, data does not yet point to the fact that this necessitates marriage and this should be clearly conveyed in sex education. As we increase our understanding of the neural underpinnings of love and sexual motivations and behavior, we will continue to gain a better understanding of how these experiences and motivations affect the developing adolescent brain as well as the brain throughout the life course in order to better inform sex education efforts.

While neuroscience has expanded our understanding of the brain-chemical interactions associated with sex and love, there are still significant limitations to understanding these complex mechanisms and how they interact with the developing adolescent brain. To date, we are not aware of any studies that specifically explore the neurobiological difference between romantic love and sex among adolescents. In addition, we are not aware of any longitudinal neuroimaging studies that measure differences in neural functioning or development between adolescents who experience sex and romantic love and those who do not. Additional research is needed to explore these factors in the developing adolescent.

Despite the nascent nature of the research, on the whole, neuroscience has helped expand our understanding of the complexity of adolescent sexual and romantic relationship decision making and underscores the need to provide adolescents with comprehensive sexuality education from an early age. Emerging brain development research and neuroscience suggest that changes in rational, affective, and social processing play a critical role in influencing adolescent sexual and romantic behavior.³⁵ Despite conceptual and empirical advances in adolescent brain development and romantic and sexual decision making resulting from neuroscience, overstating

our current understanding of these advances leads to “poor recommendations based on...shaky foundations”.⁷ As we continue to make advances through both behavioral and neuroscience research about adolescent romantic relationships and sexuality, it is essential to provide adolescents with accurate, research-based information to support them in becoming sexually healthy adults. Efforts have already been made to suggest ways to translate developmental neuroscience into sex education curricula.⁴⁹ While the evidence from neuroscience does not yet allow for clear conclusions about the cost or benefits of early romantic relationships and sexual behavior, it does support the idea that providing developmentally appropriate messages that support young people in gaining knowledge and skills that contribute to life-long sexual health. The advances of neuroscience point to exciting opportunities for future research on the neurological underpinnings of adolescent romantic and sexual behavior. To date, existing research does not point to any evidence that premarital sex and relationships lead to negative life-long outcomes. As such, sex education policies and curricula contrasting this view should be revisited in an effort to ensure their accuracy. While understanding the neuroscience related to adolescent brain development, love, sex and marriage does not explain adolescent behavior, it points to new opportunities for policies and programs to best support adolescents as they navigate this critical developmental window to enhance their life-long sexual health.

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