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Review article

Genetic influences on adolescent behavior

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ABSTRACT

Adolescence is a transitional, developmental phase with marked shifts in behavior, particularly as related to risk-taking and experimentation. Genetic influences on adolescent behavior also show marked changes across this developmental period; in fact, adolescence showcases the dynamic nature of genetic influences on human behavior. Using the twin studies literature on alcohol use and misuse, we highlight several principles of genetic influence on adolescent behavior. We illustrate how genetic influences change (increase) across adolescence, as individuals have more freedom to express their predispositions and to shape their social worlds. We show how there are multiple genetic pathways to risk, and how the environment can moderate the importance of genetic predispositions. Finally, we review the literature aimed at identifying specific genes involved in adolescent behavior and understanding how identified genes impact adolescent outcomes. Ultimately, understanding how genetic predispositions combine with environmental influences to impact pathways of risk and resilience should be translated into improved prevention and intervention efforts; this remains a rich area for future research.

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1. Introduction

Adolescence represents a critical link between childhood and adulthood. It is a developmental period characterized by tremendous physical changes (e.g., growth spurt, brain development, sexual maturation), psychological development (e.g., identity development), and social role transitions. One of the hallmarks of adolescence is an increase in risk taking behavior, as adolescents increasingly experiment and engage in the world. What is perhaps less widely recognized is that there are parallel dynamic changes that occur across adolescence in the importance of genetic effects. Using the literature on alcohol use and misuse as a model, we review overarching principles regarding genetic effects on adolescent behavior.

2. Basic methodology of genetic epidemiology: an overview of twin studies

There are several methods that have been used to study genetic influences on behavior, including family, adoption, and

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twin designs, each of which has its own strengths and weaknesses (Plomin et al., 2001). We focus here on twin designs, as this has been the "work horse" of behavior genetics. The relative frequency of twins, comprising about 3 in every 100 births (Hamilton et al., 2015), and the comparative ease of obtaining them through population-based (Kaprio et al., 2002) or records based (Anderson et al., 2002; Meyer et al., 1996) registries, has made this a ready design for studying genetic influences on behavior. The basic tenet of the twin design involves comparing the similarity of different types of twins who differ in their genetic relatedness. Monozygotic twins (MZs) result from a single egg fertilized by a single sperm and, accordingly, share 100% of their genetic variation and all of their shared environment when reared together. Dizygotic twins (DZs) result from two eggs, fertilized by two sperm, and therefore share, on average, just 50% of their genetic variation (as do ordinary siblings), but also share 100% of their shared environmental influences when reared together. Accordingly, comparing the similarity of MZ and DZ twins yields information about the relative importance of genetic and environmental influences. To the extent that MZs are more alike than DZs, genetic influences are implicated. If DZs are just as similar as MZs, then shared environmental processes, such as those influences found in the shared family environment, shared peers, shared schools and neighborhoods, etc., must predominate. If MZs are not exactly identical (as they would be if an outcome were 100% genetically influenced), then unique environmental processes must play a role. These could include environmental influences that are unique to an individual, such as a particular life event, stressor, or other influence not shared with their co-twin, and/or environmental events that differentially effect the co-twins (Turkheimer and Waldron, 2000).

The twin methodology can be applied to the study of virtually any behavior of interest, and probably has: a vast literature surrounds twin studies of psychopathology (Hewitt et al., 1997; McGue et al., 2006), personality (Littlefield et al., 2011; Viken et al., 2007), cognitive ability (Plomin and DeFries, 1998; Trzaskowski et al., 2013), as well as other behaviors that may seem more surprising, such as divorce (McGue and Lykken, 1992), voting behavior (Eaves et al., 1999; Hatemi et al., 2015), and well-being and life satisfaction (Archontaki et al., 2013; Sadler et al., 2011). This brings us to what has been called the first law of behavior genetics (Turkheimer, 2000): "all human behavioral traits are heritable." A good rule of thumb is that if you have to guess to what extent something is genetically influenced, a good guess is that "it" is about 50% heritable, regardless of what the "it" is (Polderman et al., 2015).

But these static heritability estimates fail to capture the dynamic nature of genetic effects. While demonstrating that genetic influences play a role in virtually all domains of human behavior has been an important advance, it is critical to understand the mechanisms by which genetic influences exert their effects. The dynamic shifts that occur across adolescence make this an important period during which to study genetic effects; in fact, the study of adolescent behavior illustrates many of the important principles of how genetic influences operate, which we focus on here.

3. Key principles of behavior genetics

3.1. Principle 1: genetic influences change in importance across adolescence

Alcohol use is a common form of risky behavior in adolescence, and alcohol use is a developmental phenomenon. Cross-sectional and longitudinal studies of alcohol use reveal age-related patterns. Although some children begin drinking in earlier ages, alcohol use typically begins in adolescence (Faden, 2006). Between ages 12 and 21, rates of alcohol use and heavy episodic drinking increase sharply. National survey data indicate that the percentage of American youth who have ever drunk at least one whole drink rises steeply across adolescence, leveling off at about age 21 (SAMHSA, 2007). Recent national data further show that all levels of past-month alcohol use increase steadily across adolescent years, including any alcohol use, binge use, and heavy use (SAMHSA, 2014). Similarly, data from the Monitoring the Future study, a nationally representative sample of 8th, 10th, and 12th graders, demonstrate that the prevalence of binge drinking (having 5+ drinks at least once in the past two weeks) increases substantially from 8th grade to 12th grade (Johnston et al., 2016). Notably, frequency of binge drinking also increases across this developmental period. Data from the National Survey on Drug Use and Health (NSDUH) showed that the mean number of binge drinking days in the past 30 days increased continuously for both male and female adolescents from ages 12 to 20, but this rise was more dramatic for males than for females (Chen et al., 2015). Adolescence also represents an important developmental period for the development of alcohol problems. National data from NSDUH suggest that the prevalence of past-year alcohol use disorder increases between ages 12 and 17 and peaks in young adulthood, between ages 18 and 25 (SAMHSA, 2014).

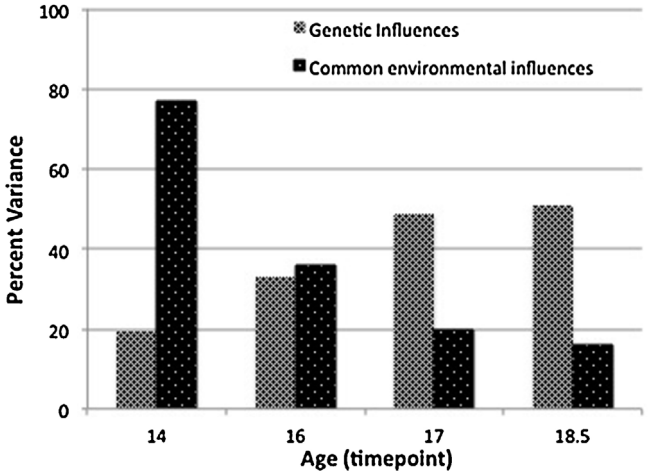

Fig. 1. Data from the Finnish twin studies demonstrating the changing degree of genetic and environmental influences across adolescence (Rose et al., 2001a; Rose et al., 2001b): genetic influences become more important, and common environmental influences become less important.

In the same way that alcohol use behavior shows dynamic change across the period of adolescence, twin studies demonstrate that the importance of genetic and environmental influences on alcohol use also change dramatically over this developmental period. Data from two population-based longitudinal Finnish twin studies illustrate the striking shift in the relative importance of genetic and environmental influences that occurs from early adolescence to young adulthood (Fig. 1): there is a steady increase in the relevance of genetic factors on alcohol use across adolescence, and a corresponding and sharp decrease in the relevance of common environmental influences (Rose et al., 2001a, 2001b). These data demonstrate that while alcohol initiation is largely environmentally influenced, as has also been found in numerous other twin studies (Hopfer et al., 2003), as drinking patterns become more regular and established across adolescence, genetic factors assume increasing importance; however, alcohol use early in adolescence is influenced largely by family, school, and neighborhood factors (Rose et al., 2001b, 2003). A very similar pattern of results for alcohol use was obtained by a life history method in male twin pairs from the Virginia Adult Twin Study of Psychiatric and Substance Use Disorders (Kendler et al., 2008b). At age 14, all twin resem-