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Examining the link between adolescent brain development and risk taking from a social–developmental perspective

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ABSTRACT

The adolescent age period is often characterized as a health paradox because it is a time of extensive increases in physical and mental capabilities, yet overall mortality/morbidity rates increase significantly from childhood to adolescence, often due to preventable causes such as risk taking. Asynchrony in developmental time courses between the affective/approach and cognitive control brain systems, as well as the ongoing maturation of neural connectivity are thought to lead to increased vulnerability for risk taking in adolescence. A critical analysis of the frequency of risk taking behaviors, as well as mortality and morbidity rates across the lifespan, however, challenges the hypothesis that the peak of risk taking occurs in middle adolescence when the asynchrony between the different developmental time courses of the affective/approach and cognitive control systems is the largest. In fact, the highest levels of risk taking behaviors, such as alcohol and drug use, often occur among emerging adults (e.g., university/college students), and highlight the role of the social context in predicting risk taking behavior. Moreover, risk taking is not always unregulated or impulsive. Future research should broaden the scope of risk taking to include risks that are relevant to older adults, such as risky financial investing, gambling, and marital infidelity. In addition, a lifespan perspective, with a focus on how associations between neural systems and behavior are moderated by context and trait-level characteristics, and which includes diverse samples (e.g., divorced individuals), will help to address some important limitations in the adolescent brain development and risk taking literature.

1. Introduction

The adolescent age period is often characterized as a health paradox because it is a time of extensive increases in physical and mental capabilities, yet overall mortality/morbidity rates increase significantly from childhood to adolescence (Casey & Caudle, 2013; Dahl, 2004). Moreover, the primary causes of death and disability among adolescents are not related to disease, but rather to preventable forms of injuries (e.g., unintentional injuries, suicide, and homicide), and are linked to involvement in health-risk behaviors such as substance use and delinquency (Dahl, 2004). While extensive research has been conducted examining how the social context (e.g., peer and family influence) and individual differences in personality factors (e.g., sensation-seeking, impulsivity) are linked to adolescent risk taking behaviors (e.g., Donohew et al., 2000; Romer, Betancourt, Brodsky, Giannetta, & Yang, 2011), more recently researchers have started to focus on how adolescent brain development might be implicated in these behaviors (e.g., Steinberg, 2008; Telzer, Fuligni, Lieberman, & Galván, 2013).

Models of adolescent brain development such as the Dual Systems Model (see Steinberg, 2008) suggest that adolescents may experience a temporal gap between a relatively early maturing affective/approach system and a slower maturing cognitive control system (e.g., Ernst, Pine, & Hardin, 2006; Geier & Luna, 2009). The early maturing affective/approach system is hypothesized to be a result of increases in dopaminergic activity and subcortical brain structures such as the ventral striatum, perhaps linked to puberty, leading to increases in reward seeking and need for novelty (see also the Triadic model for a further distinction between the approach/reward and avoidance/emotion systems; Ernst et al., 2006). In contrast, the slower maturing cognitive control network is hypothesized to be led by the prefrontal cortex, responsible for planning, judgment, and inhibition, and is thought to not be fully mature until the mid-20s (Ernst et al., 2006; Galvan et al., 2006). Neural connections among brain regions also continue to strengthen across adolescence into young adulthood (Dosenbach, Petersen, & Schlaggar, 2013; Eluvathingal, Hasan, Kramer, Fletcher, & Ewing-Cobbs, 2007; Paus, 2009). This asynchrony in developmental time courses between the affective/approach and cognitive control

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systems, and the ongoing maturation of neural connectivity are thought to lead to increased vulnerability for risk taking (Casey, Getz, & Galvan, 2008; Ernst, this issue; Giedd, 2004; Steinberg, 2008; but see Pfeifer & Allen, 2012, for a critique of this hypothesis), particularly during the middle adolescent period (Steinberg, 2008). Adolescents are thought to be at risk particularly in situations in which they feel high arousal (e.g., when they are with their peers, and/or in emotionally salient situations (Casey, Jones, & Somerville, 2011; Ernst, Romeo, & Andersen, 2009; Geier & Luna, 2009; Hare et al., 2008; Steinberg, 2008). These new insights into adolescent brain development have played a critical role in increasing our understanding of adolescent engagement in risk taking behaviors.

The focus of the present article is to highlight relevant social developmental research on risk taking across the lifespan in order to add to the current discussion regarding the link between adolescent brain development and risk taking, as well as to offer a few suggestions for how future research in this area might be harnessed to increase our understanding of risk taking behaviors. We focus specifically on the following questions: (a) Are the increases in mortality and risk taking behaviors from childhood to adolescence as dire as often implied? (b) Does the peak age of involvement in real-world risk taking correspond to predictions based on the Dual Systems Model of adolescent brain development? (c) Is risk taking necessarily unregulated? and (d) What differs between adolescent and adult risk taking?

2. Question 1: Are the increases in mortality and risk taking from childhood to adolescence as dire as often implied?

2.1. National statistics on mortality

Significant increases in mortality and morbidity from childhood to adolescence have been documented in Western culture (e.g., National Vital Statistics Reports, 2012), a fact that has been repeated often by researchers studying risk taking in adolescence (e.g., Casey & Caudle, 2013; Dahl, 2004; Geier, Terwilliger, Teslovich, Velanova, & Luna, 2010). Rarely mentioned, however, is that although mortality increases from childhood to adolescence in these cultures, very few children or adolescents die. As presented in Fig. 1, the crude rate of deaths in 2005 for 10–14 year old Canadian children, for example, was 4.9 per 100,000 population, or 0.0049%. Similarly, in the US the crude rate of deaths in 2009 for 10–14 year olds was 6.8 per 100,000 population, or 0.0068% – see Fig. 2. In adolescence

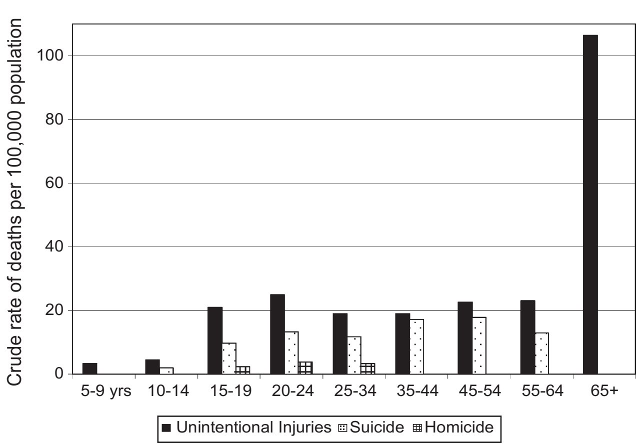

Fig. 1. Death rates per 100,000 population in Canada, 2005. Suicide rates unavailable for people aged 65 years and above, and homicide rates unavailable for people aged 35 years and above. Adapted from Public Health Agency of Canada. Retrieved from http://www.phac-aspc.gc.ca/publicat/lcd-pcd97/table1-eng.php.

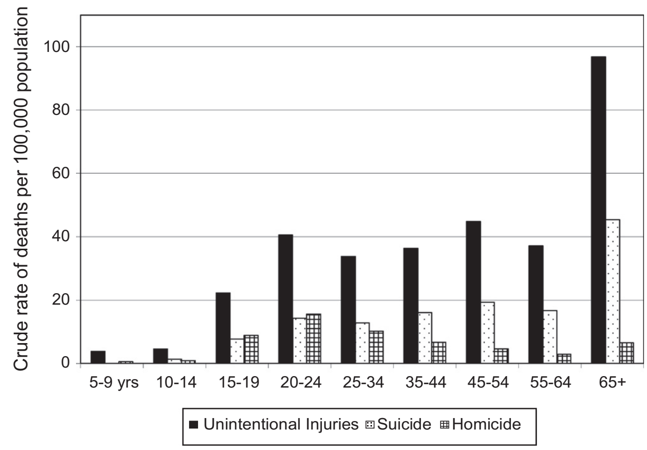

Fig. 2. Death rates per 100,000 population in United States, 2009. Adapted from National Vital Statistics Reports, Vol. 60, No. 3, and Vol. 61, No. 7, October 26, 2012.

(i.e., from 15 to 19 years of age), these rates climbed to 33.1 per 100,000, or 0.0331%, in Canada, and 38.9 per 100,000, or 0.0389% in the US. While these increases are significant, and of course every death in that age group is tragic, the mortality rate for adolescents in these countries is still less than 1/20 of one percent. In other words, the survival rate of high school students in North America is an impressive 99.96%. Note also that the death rate continues to rise in emerging adulthood, and therefore, is not particularly characteristic of adolescence.

2.2. National statistics on morbidity

Moreover, traditional morbidity measures indicate that relatively few children and adolescents experience disease, such as cancer and heart disease. There are significant increases, however, in unintentional injuries from childhood to adolescence. For example, in the US, 14,490 youth (per 100,000 population, or 14.49%) aged 15–19 were treated for unintentional injuries in hospital emergency departments in 2005, in contrast to 11,228 youth aged 10–14 (per 100,000 population, or 11.23%) – see Fig. 3. In addition, specifically in terms of inpatient hospitalizations, in 2005 the rate for unintentional injuries was 464 per 100,000 population for 15–

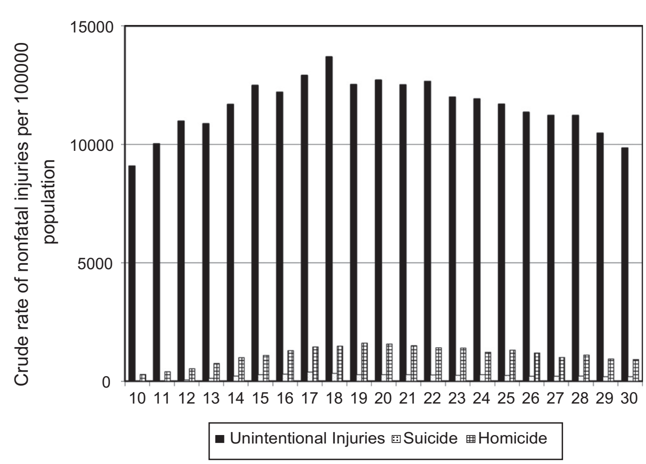

Fig. 3. National estimates of injuries per 100,000 population treated in U.S. hospital emergency departments for 2005. Adapted from National Center for Injury Prevention and Control. *Data source*: NEISS All Injury Program operated by the Consumer Product Safety Commission for numbers of injuries. Bureau of Census for population estimates.

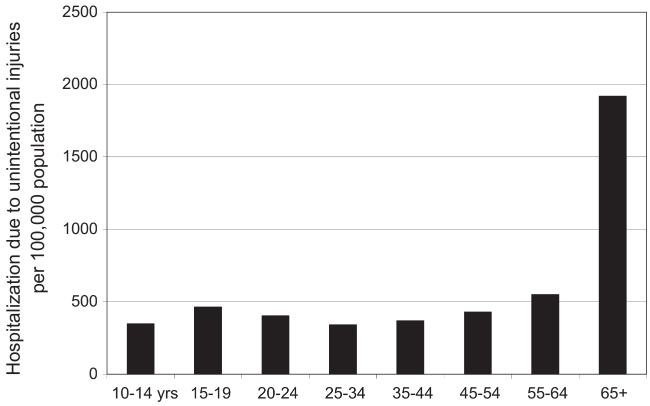

Fig. 4. Rates of hospitalization due to unintentional injuries per 100,000 population in Canada, 2005. Adapted from the Public Health Agency of Canada. Retrieved from http://dsol-smed.phac-aspc.gc.ca/dsol-smed/is-sb/leadcauses/leading_causes_hosp_2005-eng.pdf.

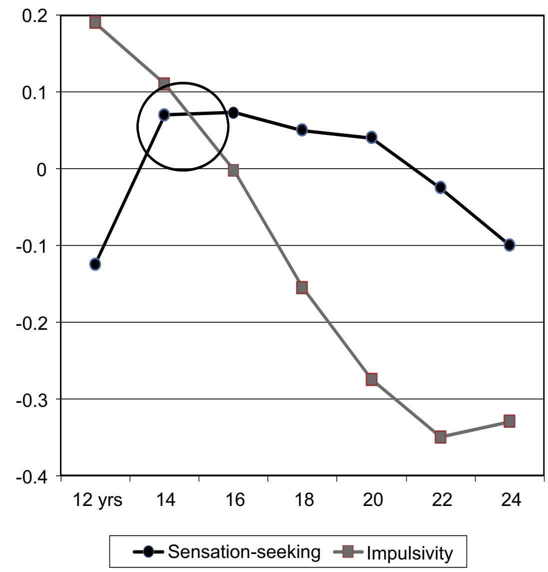

Fig. 5. Change over time in self-reported sensation-seeking and impulsivity. Measured longitudinally across age. Section of lines within the circle represents age period (i.e., 14–16) at which hypothesized vulnerability for risky behavior should be greatest – see Steinberg, 2008. Adapted from "Individual Differences in the Development of Sensation Seeking and Impulsivity During Adolescence: Further Evidence for a Dual Systems Model," by K. P. Harden & E. M. Tucker-Drob, 2011 *Developmental Psychology*, *47*, p. 742.

19 year old Canadian youth (i.e., 0.464%), in contrast to 349 hospitalizations per 100,000 population for 10–14 year old Canadian youth (0.349%) – see Fig. 4. To put these statistics in context, the increase in injuries from childhood to adolescence is thought to be at least partially due to the increased frequency and intensity of involvement in organized sports by high school students (Cheng et al., 2000), in addition to workplace-related accidents (e.g., Estes, Jackson, & Castillo, 2010) and motor vehicle accidents. For example, being struck by an object or person, falls, motor vehicle-occupant accidents, and overexertion were the four leading causes of unintentional injuries in 2006 in which US adolescents aged 15–19 were treated in hospital emergency departments and released (Centers for Disease Control, 2006). Again, however, while these are significant increases, the rate of serious injuries for adolescents is very low.

Given the actual mortality/morbidity statistics, we may question whether the often reported significant increase in mortality that occurs from childhood to adolescence is truly as dire a situation as some might claim. The emphasis on the increasing mortality/morbidity rates from childhood to adolescence corresponds to the traditional research focus on a deficit-model of youth, in which the primary attention has been on "problem" youth and adolescent risk taking (Bell & Bell, 1993; King, Fleming, Monahan, & Catalano 2011). Yet, the reality is that most youth go through adolescence without experiencing any major problems (Arnett, 1999), a fact that is represented not only in the low rates of mortality/morbidity in adolescence, but also brought to the forefront of current adolescent research with the advent of interest in adolescent "health," "thriving," and "positive youth development" (Benson & Scales, 2009; Lerner et al., 2013). Thus, we concur with Casey and Caudle (2013) and Johnston, O'Malley, Bachman, and Schulenberg (2009) that although adolescent risk taking behaviors are an important issue, we should not exaggerate the health risks faced by youth today.

3. Question 2: Does the peak age of involvement in real-world risk taking correspond to predictions based on the Dual Systems Model of brain development?

Similar to unintentional injuries, there is a widely held perception by researchers, media, and policy makers that high rates of risk taking, such as substance use, reckless driving, and sexual risk taking, are more common during adolescence than at any other age period (e.g., Dahl, 2004; Galvan, 2013; Somerville, Jones, & Casey, 2010; Steinberg, 2005). Indeed, according to the Dual Systems Model of adolescent brain development, the peak age of potential for risky behavior should be in *middle adolescence*, when the discrepancy between the early maturing affective/approach network (i.e., sensitivity to affective and motivational cues) and the later maturing cognitive control network (i.e., ability to inhibit, plan, and regulate) is most pronounced (see Steinberg, 2008). Furthermore, behavioral longitudinal studies assessing changes in sensation seeking (relating to the affective/approach network) and impulsivity (relating to the cognitive control network) across age also support this contention (see also Galvan, Hare, Voss, Glover, & Casey, 2007; Harden & Tucker-Drob, 2011; Leshem & Glicksohn, 2007; Steinberg et al., 2008). For example, Harden and Tucker-Drob (2011) found that sensation seeking and impulsivity showed differing developmental trajectories (see Fig. 5). Specifically, sensation-seeking increased in preadolescence, peaked in middle adolescence, and then declined before leveling off in emerging adulthood. In contrast, impulsivity gradually declined across adolescence. Thus, as Fig. 5 illustrates (note the circled age period), around age 15 – when the combination of sensation seeking and impulsivity are at their highest - should be the peak age for risk taking.

But does this proposed peak age of potential for risky behavior (i.e., 15 years) map onto real-world patterns of adolescent risk taking? In other words, does *vulnerability* translate into actual risk taking behaviors? Much of the research on adolescent brain development has not specifically examined associations between real-world risk taking behaviors and activity in the affective/approach vs cognitive control systems (Dahl, 2011; Johnston, Blum, & Giedd, 2009; Pfeifer & Allen, 2012). In fact, proponents of dual systems theory acknowledge that there is to date little empirical evidence linking neurobiological changes to real-world behavior, and that at present the Dual Systems Model is "reasonable speculation" (Steinberg 2008, p. 81). In the absence of an extensive body of literature examining the associations between brain development and changes in risk taking over time, it is important to consider longitudinal research on changes in risk taking behaviors across adolescence in order to determine whether real-world risk taking peaks in middle adolescence.

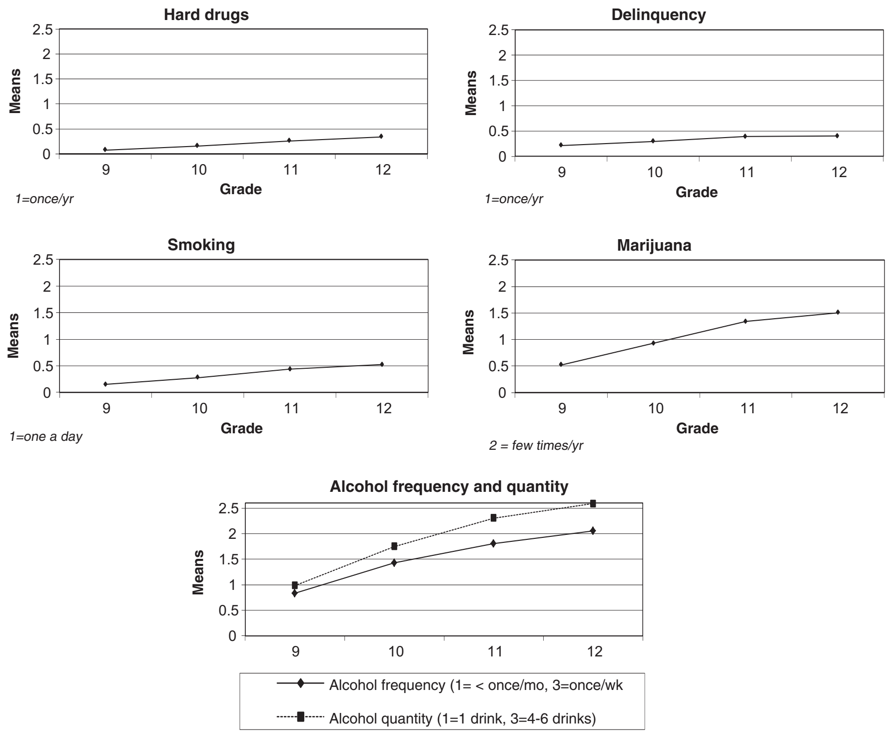

Fig. 6. Change in frequency of health risk behaviors across high school grades. Means for depressive symptoms, alcohol frequency and amount, smoking, marijuana, hard drugs, and delinquency, across four years in high school. Means are adjusted scores. Reprinted from *Journal of Adolescent Health, 50*, Hooshmand, S., Willoughby, T, & Good, M. Does the Direction of Effects in the Association Between Depressive Symptoms and Health-Risk Behaviors Differ by Behavior? A Longitudinal Study Across the High School Years, 140–147.

Studies on rates of risk taking across adolescence and young adulthood do not provide unequivocal support for the Dual System Model hypothesis that risk taking should be most common among 15 year olds. In a recent longitudinal study published from our lab (Hooshmand, Willoughby, & Good, 2012), we examined engagement in a variety of risk taking behaviors (i.e., alcohol frequency and quantity, cigarette smoking, marijuana, hard drug use, and delinquency) across the high school years (i.e., grades 9, 10, 11, 12) with a sample of 4412 adolescents. Growth curve analyses of engagement in risk taking behaviors over time indicated that, on average, youth reported low levels of involvement in these behaviors, with the exception of alcohol use in senior grades. Moreover, engagement in all the behaviors (including alcohol) showed gradual increases across the high school years, rather than peaking in middle adolescence. Specifically, the highest alcohol frequency and quantity (i.e., binge drinking), cigarette smoking, marijuana use, hard drug use and delinquency scores in the study were reported in grade 12, when adolescents were 17 or 18 years of age on average (see Fig. 6), a finding which is inconsistent with the prediction about the developmental course of risk taking engagement proposed by the Dual Systems Model.

Moreover, researchers have found that the highest levels of risk taking often occur among emerging adults, particularly university/college students. Using alcohol consumption as an example, in our longitudinal sample of over 1000 first year undergraduate students followed from first to second year of university, students reported higher frequency of alcohol use as well as higher levels of binge drinking than our high school student sample (Willoughby, 2013; see Fig. 7).[2] Importantly, these results are consistent with nationally representative studies in the US (e.g., Monitoring the Future Study, Johnston, O'Malley, Bachman, & Schulenberg, 2009 – see Fig. 8), as well as a host of other studies which indicate that alcohol use peaks

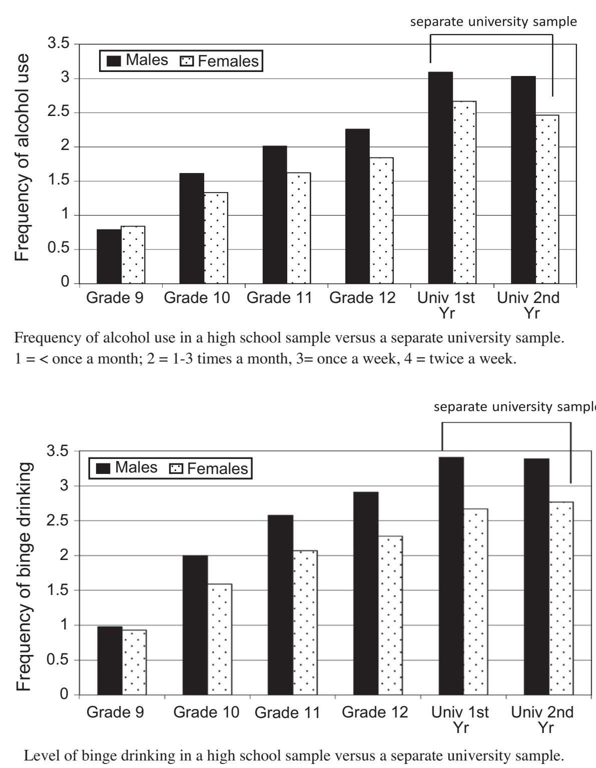

Fig. 7. Frequency of alcohol use and level of binge drinking in a high school sample versus a separate university sample. Willoughby, 2013.

[2] We found similar patterns of engagement for other risk taking behaviors as well, including marijuana use, illicit drug use, and aggression. For simplicity, results are presented in Figs. 7 and 8 for frequency of alcohol use and binge drinking only.

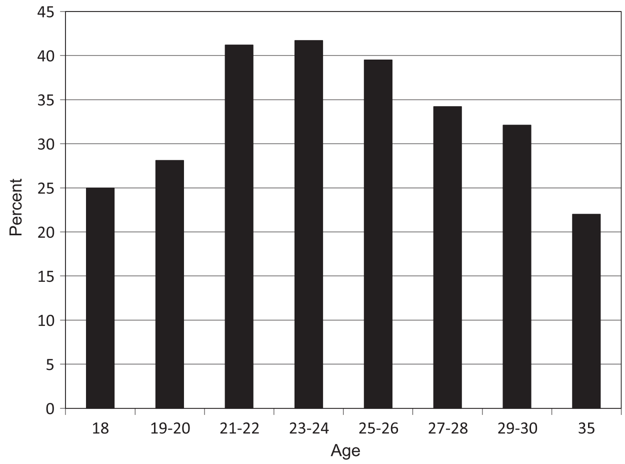

Fig. 8. Age differences in 2-week Prevalence of 5 or More Drinks in a Row. Adapted from "Monitoring the Future National Survey Results on Drug Use, 1975–2009. Volume II: College Students and Adults Ages 19–50," by L. D. Johnston, P. M. O'Malley, J. G. Bachman, & J. E. Schulenberg, 2010, Bethesda, MD: National Institute on Drug Abuse, p. 305.

in emerging adulthood, particularly among university/college students (Chassin, Pitts, & Prost, 2002; Fromme, Wetherill, & Neal, 2010; Mahalik et al., 2013; O'Malley and Johnston, 2002). Furthermore, in a cross-sectional study of 282 individuals, aged 10–30, Shulman and Cauffman (2013) found that the peak age for most favorable attitudes toward risk occurred at ages 20 and 21 when participants were asked to make quick, intuitive assessments of risk behavior (see also Fig. 3 which indicates that the peak age for treatment of unintentional injuries in hospital emergency departments in 2005 was 18 years).

The fact that university/college students exhibit the highest levels of many risk taking behaviors is an interesting paradox. Given that adolescents who attend university/college have demonstrated academic success in high school, it would be expected that these individuals would have higher levels of cognitive control and engage in less risk taking in high school than their peers who do not go onto university/college. Indeed, researchers have reported a filtering effect, in which high school graduates who go on to pursue university/college are differentiated from their peers by lower impulsivity, lower risk taking, and greater academic achievement during the high school years (Schulenberg & Parick, 2012; Slutske, 2005; Stanford, Greve, Boudreaux, Mathias, & Brumbelow, 1996). Yet, although future university/college students engage in lower levels of risk taking than their peers during the high school years, they go on to *surpass* the drinking behaviors of their non-university/college classmates in emerging adulthood (Johnston, O'Malley, Bachman, & Schulenberg, 2009; O'Malley and Johnston, 2002). The discrepancy between adolescent and young adult risk taking highlights the importance of understanding how the social context may constrain and/or facilitate risk behavior. While the dual system model emphasizes that vulnerability to risk taking might be highest in middle adolescence, it is no surprise that the environment plays a huge role in whether this vulnerability is translated into actual risk behaviors.

There also have been significant declines in risk taking over the past several decades, again drawing attention to the importance of social context. For example, findings from the Monitoring the Future study of US adolescents indicate a significant decline in the use of alcohol and other drugs since 1980, when they started their study (Johnston, O'Malley, Bachman, & Schulenberg, 2012). Importantly, this decline in risk taking behaviors is not only limited to adolescents in the US (or just to substance use – mortality and youth crime rates also have declined – see Pinker, 2011 on how violence has declined over the course of history). Data from Ontario, Canada, indicate that among Canadian high school students assessed from 1977 to 2011, there have been significant declines in alcohol use, driving after drinking alcohol, cigarette smoking, and illicit drug use (Paglia-Boak, Adlaf, & Mann, 2011). Similar declines, although not as pronounced, also have been noted among emerging adults – see Fig. 9.

The reasons for these declines likely are complex and multi-faceted. While some of the US decreases in alcohol use might be attributed to the legal drinking age being changed to age 21 in 1984 (Hedlund, Ulmer, & Preusser, 2001), this explanation likely does not account for most of the change given that the declines were apparent already in 1980. In addition, Canada also has experienced declines in high school student substance use since the 1970s, and their legal drinking age remained consistent at age 19 throughout this time period (in 3 of the 10 provinces, the legal drinking age is 18). Furthermore, graduated licensing policies and zero tolerance laws were not introduced until the 1990s in the US and Canada, so these policy changes also cannot explain the decline between 1977 and the 1990s. One potential explanation for the decline in risk taking over the past 30 years might be that increasingly youth today are going on past high school to university/college and delaying becoming independent from their parents, finding a partner, getting married, and having children until their mid to late 20s. Evolutionary theories of risk taking (and also data from risk taking studies of divorced individuals; Daly & Wilson, 2001) suggest that risk taking may be adaptive when seeking mates and independence (e.g., see Ellis et al., 2012); thus, risk taking, particularly in the high school years, is perhaps less adaptive for young people today than it would have been in the 1970s.

Another likely explanation may be changes in social norms over time (Pinker, 2011). For example, groups such as MADD ("mothers against drunk driving") and SADD ("students against drunk driving," now "students against destructive decisions"), started in 1980 and 1981, respectively. Their warnings about the danger of drinking and driving have become common knowledge across North America, and recent statistics indicate that young people in particular seem to have received the message. For example, US and Canadian statistics indicate that the number of young drinking drivers in fatal crashes has declined more rapidly than the number of older drinking drivers (Hedlund et al., 2001). Furthermore, stu-

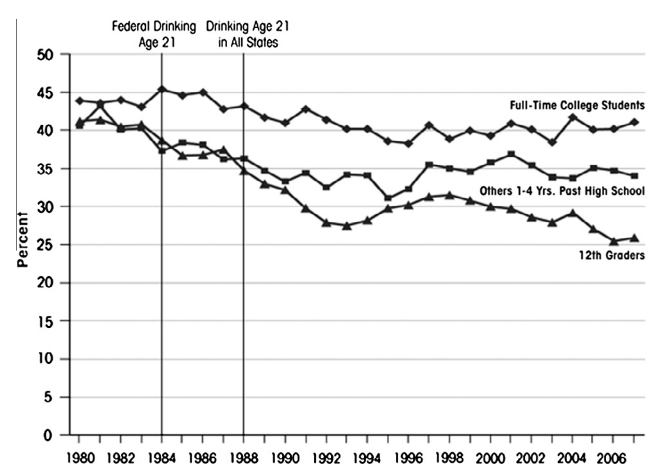

Fig. 9. Trends in two-week prevalence of five or more drinks in a row among 12th graders, college students, and others one to four years beyond high school. Adapted from "Monitoring the Future National Survey Results on Drug Use, 1975–2006. Volume II: College Students and Adults Ages 19–45," L. D. Johnston, P. M. O'Malley, J. G. Bachman, & J. E. Schulenberg, 2007, Bethesda, MD: National Institute on Drug Abuse, p. 307.

dents in schools with very active SADD-based programs tend to report more negative attitudes towards drinking and driving relative to comparison schools with no active SADD-based programs (Leaf & Preusser, 1995). It is important to emphasize, however, that there is little direct evidence for the effectiveness of such programs on risk taking; as a result, the causes of the decline in risk taking among adolescents remains speculative (Hedlund et al., 2001).

Significant declines in risk taking over such a short period of time (i.e., from the late 1970s to now), as well as the higher rates of risk taking in emerging adulthood than in adolescence, suggest that our understanding of adolescent brain development has to be placed in juxtaposition with the role of the social environment. It will be important in future research to examine these interactions more closely in order to ascertain how various social contexts (e.g., differences in normative attitudes toward risk across cohorts of youth) may moderate the associations between adolescent brain development and risk taking behavior. Such research would help us to understand why adolescents (who may be at heightened risk for engaging in harmful activities) engage in relatively low levels of risk taking, while university students (whose risk for these behaviors should be lower than adolescents) report higher levels of many risk taking behaviors, on average, than adolescents. Another aspect of the risk taking experiences of adolescents that a focus on social context may help us to understand is the phenomenon of *regulated* risk taking. It is to this important and relatively neglected issue that we turn next.

4. Question 3: Is risk taking necessarily unregulated?

One of the assumptions of adolescent brain development models (e.g., Dual Systems Model; Triadic Systems Model) is that risk taking in adolescence is often impulsive, in that it results from a lack of self-control (i.e., adolescents have difficulty regulating their impulses to engage in risky behavior due to an immature cognitive control system, particularly under conditions of high arousal; Steinberg, 2008). We contend, however, that risk taking is not necessarily unregulated or impulsive, and instead might be *planned* in certain contexts. Specifically, adolescents may deliberately engage in risk taking behavior in order to gain social rewards, such as interpersonal acceptance (Rawn & Vohs, 2011). According to Rawn and Vohs, planned risk taking may even require the *exertion* of self-control in order to overcome aversions to risky behavior, such as the distaste for alcohol or cigarettes, or the fear of negative consequences from having unprotected sex or using illicit drugs. Alcohol consumption, in particular, may have strong social rewards for adolescents and emerging adults. Specifically, a salient developmental task among adolescents is developing strong friendships (e.g., Havighurst, 1948/1972), and alcohol consumption may facilitate the successful carrying out of this task by easing social inhibitions and encouraging social acceptance from peers who consume alcohol. For example, researchers have shown that adolescents' expectations of social benefits of alcohol consumption (Smith, Goldman, Greenbaum, & Christiansen, 1995) positively predicted their frequency of alcohol consumption over two years. In addition, even people who dislike alcohol are more likely to drink if they believe that their friends enjoy alcohol, compared to if they believe that their friends also dislike alcohol (Rawn & Vohs, 2011). Thus, although adolescents may consume alcohol due to a lack of impulse control, they also may deliberately plan to drink, even in spite of aversions to alcohol, in order to gain social benefits.

The perceived social benefits of alcohol consumption may be particularly relevant today for emerging adults, who face the developmental task of finding a romantic partner (e.g., Roisman, Masten, Coatsworth, & Tellegen, 2004). As alcohol can help alleviate social inhibitions, emerging adults may plan to drink in order to increase their confidence in conversations and to facilitate social behaviors such as going to night clubs and dancing (e.g., Roehling & Goldman, 1987), which, in turn, may help them meet potential romantic partners. Furthermore, emerging adults, particularly those who pursue a post-secondary education, have many opportunities to exploit the social benefits of alcohol consumption, as alcohol is available in most social contexts in college/university (e.g., parties, bars, campus pubs) and many college/university students view alcohol consumption as a normative behavior (Borsari & Carey, 2003; White & Jackson, 2004).

To date, however, research on the prevalence of impulsive versus planned risk taking is relatively scarce. It remains unclear whether, and under what conditions, risky behavior among adolescents and emerging adults is more likely to be impulsive, planned, or a combination of both (e.g., alcohol consumption is planned but then an excessive amount of alcohol is consumed due to a lack of self-control). In addition, it is unclear whether the amount of planned versus impulsive risk taking differs between adolescents and emerging adults. Considering that alcohol consumption is a more normative behavior among emerging adults than adolescents, emerging adults may be more likely than adolescents to plan to consume alcohol in order to gain social benefits. Hence, research investigating planned versus impulsive risk taking among adolescents and emerging adults is needed.

5. Question 4: What differs between adolescent and adult risk taking?

While the previous section explored how risk taking behavior in adolescence may not always be the result of *unregulated* decisions, here we draw attention to the fact that unregulated (i.e., emotional, impulsive) risk taking resulting in harmful consequences is not limited to adolescence. Although adolescent brain development models suggest that adolescence might be the age at which individuals may be most vulnerable to risk taking behaviors, particularly in the presence of strong emotions or high arousal (Steinberg, 2005), adults also engage in risk taking.

One does not have to look far to see that affective impulses and reward seeking, combined with lapses in self-control, are evident also among adults, and can incur significant costs to individuals and society. Overeating and lack of exercise, for example, can be considered self-control failures that have contributed to the obesity epidemic among adults (Hedley et al., 2004) that is shortening lives and straining health care systems worldwide (Mokdad et al., 2001). Millions of adults engage in impulse buying (Vohs & Faber, 2007), adding to their financial woes (The Canadian Press, 2012). Gambling and marital infidelity among adults are risk taking behaviors that can have wide-ranging consequences, from depression to divorce (e.g., Cano & O'Leary, 2000; Wiederman, 1997). Risk taking also is a part of older adults' lives, including those over 65 years (Rush, Murphy, & Kozak, 2012). For example, risky sexual behaviors, such as inconsistent condom use during sexual activity, have been reported among a sample of sexually active older single adults aged 50–74 years who were not in committed relationships (Foster, Clark, Holstad, & Burgess, 2012). Approximately 11% of new HIV infection diagnoses in the US occur in adults aged 50 or older (Brooks, Buchacz, Gebo, & Mermin, 2012). In addition, Liddon, Leichliter, Habel, and Aral (2010) found lower rates of condom use among divorced/separated women relative to never married women. In terms of financial risks, one experimental study of adults aged 25–75 years found that greater preference for a competitive payment schedule involving greater financial risk (i.e., $0.50 per solved item if overall score is greater than that of a randomly selected opponent, but $0 otherwise) versus a piece-rate payment schedule (i.e., $0.25 per solved puzzle, solo condition) increased across age and peaked at age 50 (Mayr, Wozniak, Davidson, Kuhns, & Harbaugh, 2012). And in parallel with our suggestion that adolescents can engage in regulated or planned risk taking (see previous section), the recent economic crisis was caused, at least partially, by bankers and individuals with poor credit ratings who made risky financial decisions (likely involving planned risk taking) in the face of temptation for large profits and home ownership, respectively (Angelides et al., 2011).

Why do adults engage in risk taking activities – to such destructive ends – if, according to theories of adolescent brain development, they should have more mature cognitive control systems than adolescents, that more consistently override impulses and temptations? The assumption of the Dual Systems Model that there are two systems that interact to govern human behavior is consistent with dual process models of decision making, which have been studied extensively with adult populations in the fields of social/cognitive psychology and behavioral economics (e.g., Evans & Stanovich, 2013; Hofmann, Friese, & Strack, 2009; Kahneman, 2011; Slovic, Finucane, Peters, & MacGregor, 2002; Strack & Deutsch, 2004). Dual process decision-making models posit that there is a fast, intuitive, automatic system, which is often reliant on affect and current emotions for making decisions ("system 1"), versus a slow, controlled, and reflective system ("system 2"). Importantly, researchers in these fields have shown that adults engage in many errors of judgment and choice (e.g., Kahneman, 2011; Slovic et al., 2002). Moreover, while system 1 is thought to be the source of many of the errors and biases for adults (as well as for adolescents), system 2 processing also is not immune to errors and biases (see Evans & Stanovich, 2013; Kahneman, 2011).

Researchers have been particularly interested in determining under what situational and dispositional conditions decision-making is driven by system 1 versus system 2 (Hofmann et al., 2009). One example of a particularly intriguing line of research is the finding that impulses and emotions tend to control behavior under conditions where adults very recently have exerted willpower or self-control (i.e., under conditions of *ego depletion,* Muraven, Tice, & Baumeister, 1998*)*. For example, Hofmann and colleagues (Friese, Hofmann, & Wanke, 2008; Hofmann, Rauch, & Gawronski, 2007) reported that consumption of unhealthy substances (i.e., candy, beer, potato chips) was best predicted by system 1 (i.e., participants' non-conscious impulses/temptation towards candy, beer, or chips) under conditions of ego depletion, but, for participants who were not depleted, explicit dietary restraint standards (i.e., system 2) best predicted the amount of unhealthy substances consumed. Similarly, adults who were depleted of self-control resources in a lab setting were more willing to buy impulsively and to spend more money on a variety of products than adults who were not depleted (Faber & Vohs, 2004). Inzlicht and Gutsell (2007) found similar results in an electroencephalographic (EEG) study, in that participants' neural system for conflict monitoring was depleted subsequent to the exertion of self-control on an unrelated task. As Kahneman (2011) points out, depletion can be caused by a wide variety of situations, such as trying to present oneself in a positive way, inhibiting natural emotional or behavioral responses, or avoiding certain thoughts.

Another example of research examining under what situational and dispositional conditions decision-making is driven by system 1 versus system 2 is research exploring *individual differences in trait-level characteristics* (Hofmann et al., 2009). Hofmann and colleagues suggest that the extent to which adult behavior is guided by system 1 or system 2 is dependent upon individual difference factors such as trait self-control and working memory capacity (see also Evans & Stanovich, 2013). More specifically, studies have found that the behavior (e.g., consumption of unhealthy substances, expressions of anger), of people low in self-control or working memory is predicted by impulses to a greater extent than individuals with higher self-control or working memory capacity (Friese & Hofmann, 2008; Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008).

Although we have provided only a brief glimpse of a voluminous and complex body of literature, it is clear that at the most basic level, adults – similar to adolescents – under some conditions, make decisions based on reason and careful deliberation, and under other conditions, make decisions based on emotions, intuition, and temptations. Indeed, age differences in risk taking may be due less to asynchrony in brain development timelines than to the particular situations that adults versus adolescents find tempting or rewarding (beyond, of course, the obvious explanation for age differences in risk taking being due, in part, to differences in experience). Given the vastly different social worlds in which teenagers and adults live, it seems reasonable to hypothesize that the situational factors that affect whether decision-making is driven by system 1 or system 2 may differ for adolescents as compared to adults. Recent research indicates, for example, that the presence of peers is a situational condition – for adolescents, but not adults – that increases the likelihood of system 1 directing an individual's behavior (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Gardner & Steinberg, 2005). Although it has yet to be addressed systematically in the research literature, it is possible that some situations cause greater depletion and subsequent self-control failures in *adults* as compared to adolescents. A particularly interesting area for future research is to examine how neural systems implicated in the dual system model might be differentially affected at different ages across the lifespan by various situational or trait-level conditions. For example, Braver, Paxton, Locke, and Barch (2009) found age differences in cognitive control neural responses in a study comparing emerging adults (undergraduates) and older adults (>72 years), but importantly, also flexibility *within* individuals as a function of task conditions and behavioral goals.

Framing research in terms of how various factors affect the strength with which system 1 versus system 2 govern decision-making across the lifespan also may allow us to more accurately characterize the individual variability in traits that predict impulsive risk taking. If low self-control or the presence of peers are framed as variables that might lead to impulsive behavior at all ages, implicit within this explanation is the fact that some adolescents have very high self-control and/or are very unaffected by their peers, and some adults have very low self-control and/or are extremely impacted by the presence of friends. Such an approach might lead to a "dimensional difference" explanation, which might emphasize that both adolescents and adults engage in risk taking (albeit in different forms), and that adolescents and adults differ quantitatively on a number of factors (both situational and dispositional) that may differentially predict whether their behavior is governed by system 1 or system 2 in various circumstances.

6. Conclusions

Adolescent brain development models, such as the Dual Systems Model (see also the Triadic Systems Model), increasingly have been used to account for the incidence of risk taking in adolescence (Ernst, this issue; Steinberg, 2005). A critical analysis of the frequency of risk taking, as well as mortality and morbidity rates across the lifespan, however, challenge the hypothesis that the peak of risk taking should occur in middle adolescence when the asynchrony between the relatively early maturing affective/approach system and the slower maturing cognitive control system is the largest (see Fig. 4; Harden & Tucker-Drob, 2011). In fact, although engagement in risk taking behaviors generally has its onset in adolescence, adolescents, on average, engage in relatively low levels of these behaviors (with the exception of alcohol use in the senior grades). Moreover, evidence from our own research indicates that young adults at university report greater frequency of risk behaviors, such as alcohol use, relative to high school adolescents, and highlights the role of social context on engagement in risk behaviors.

Although the field of developmental neuroscience has made significant contributions to our understanding of adolescent brain development, future research would benefit from a closer examination of how social context might moderate these findings. For example, engagement in some risky behaviors (e.g., binge drinking) at various life stages (e.g., young adults at university) may be purposeful and planned, as opposed to impulsive and emotionally reactive. Furthermore, in some situations, adults may engage in more impulsive behaviors and risk taking than adolescents. Thus, we need to broaden the scope of risk taking behaviors in our studies to include risks that are relevant to older adults, such as risky financial investing, gambling, and marital infidelity. This research also needs to be embedded in long-term longitudinal studies, which include diverse samples (e.g., divorced individuals). A lifespan perspective, with a focus on how associations between neural systems and behavior are moderated by both situational (e.g., context, goals) and trait-level characteristics (e.g., working memory), will help to address some important limitations in the adolescent brain development and risk taking literature. We envision numerous opportunities for studies that integrate neurobiological, psychological, and socio-cultural paradigms, which together, can advance our understanding of adolescent risk taking and better inform policies and services targeted at fostering more positive development across the lifespan.

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