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The Influences of Described and Experienced Information on Adolescent Risky Decision Making

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Abstract

Adolescents are known to take more risks than adults, which can be harmful to their health and well-being. However, despite age differences in real-world risk taking, laboratory risk-taking paradigms often do not evince these developmental patterns. Recent findings in the literature suggest that this inconsistency may be due in part to differences between how adolescents process information about risk when it is described (e.g., in a description-based classroom intervention) versus when it is experienced (e.g., when a teenager experiences the outcome of a risky choice). The present review considers areas of research that can inform approaches to intervention by deepening our understanding of risk taking in described or experienced contexts. We examine the literature on the description-experience gap, which has generally been limited to studies of adult samples, but which highlights differential decision making when risk information is described versus experienced. Informed by this work, we then explore the developmental literature comparing adolescent to adult decision making, and consider whether inconsistencies in age-related findings might be explained by distinguishing between studies in which participants learn about decision outcomes through experience versus description. In light of evidence that studies using experience-based tasks more often show age differences in risk taking, we consider the implications of this pattern, and argue that experience-based tasks may be more ecologically valid measures of adolescent risky decision making, in part due to the heightened affective nature of these tasks. Finally, we propose a model to integrate our findings with theories of adolescent risk-taking, and discuss implications for risk-reduction messaging.

Keywords

Adolescents; Risky decision making; Description-experience gap

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Introduction

Although adolescents are at the peak of their physical health, there is a spike in morbidity and mortality during the teenage years, largely from preventable behaviors connected to risky decision making (e.g., automobile crashes, delinquency, unprotected sex, binge drinking, illicit drug use; Kann et al., 2012). Accordingly, substantial resources have been invested in trying to understand why adolescents engage in such excessive risk taking, and how these behaviors might be prevented (Reyna & Farley, 2006).

While several evidence-based risk interventions have proven successful (a point to which we will return in the discussion; Downs et al., 2004; Griffin, Botvin, & Nichols, 2006; Jemmott III, Jemmott, & Fong, 2010; Kirby & Laris, 2009; Reyna & Mills, 2014), many interventions that primarily focus on providing descriptions of risk probabilities and outcomes have been less successful (Steinberg, 2008). One such program is Drug Abuse Resistance Education (D.A.R.E.), which reaches students in 75% of U.S. school districts. Despite its intuitive appeal, it has not been effective in preventing drug use (Clayton, Cattarello, & Johnstone, 1996; Ennett, Tobler, Ringwalt, & Flewelling, 1994; Singh et al., 2011; West & O'Neal, 2004). One plausible explanation for the limited efficacy of D.A.R.E. and other primarily description-based interventions is that they do not adequately consider the importance of the informational sources that guide adolescents' decisions about risk. While information acquired through instruction (i.e., explicit *descriptions* of risk outcomes) may play a role in decision making, such information may be utilized differently than information acquired through the decision-maker's own personal *experience*. In the present paper, we discuss research that explores how decision making is affected by the nature of information that informs the decision, whether through description or experience, and consider how accounting for the disparate impacts of these alternate sources might inform the development of better prevention and intervention strategies.

To construct our argument, we first briefly review relevant work from judgment and decision making (JDM) studies exploring how decision making varies after learning about risk through description alone, experience alone, and when descriptions accompany experience. This brief review focuses in particular on the Description-Experience (D-E) gap, a phenomenon that has been examined extensively in other recent reviews (see e.g., Camilleri & Newell, 2013; de Palma et al., 2014; Wulff, Mergenthaler-Canseco, & Hertwig, 2017). Despite considerable research on this phenomenon in normal adults, there is a dearth of empirical research into the relevance of the D-E gap to adolescent decision making (c.f. Rakow & Rahim, 2010; van den Bos & Hertwig, 2017; van Duijvenvoorde, Jansen, Bredman, & Huizenga, 2012).

To extend our argument, we mine a rich body of literature that explores differences between teens and adults across a diverse range of laboratory risk-taking paradigms. In doing so, we re-evaluate the developmental risk-taking literature with respect to the nature of information used in the risky-choice tasks – that is, by contrasting the findings from studies that compare adolescents to adults in tasks that explicitly describe risks to participants with those that require participants to learn about risk outcomes through accumulated task experiences.

Through this review, we demonstrate that the way in which risk information is acquired is relevant in accounting for the presence or absence of age differences in risk behavior. Based on this reassessment of the literature, we consider how the emerging patterns are addressed by existing theoretical accounts of adolescents' heightened risk taking (e.g., Steinberg, 2010; Rivers, Reyna, & Mills, 2008), and articulate an extension of prior theories to highlight the relationship between experience and the engagement of affective processes. Finally, we discuss how the pattern of findings can inform the implementation of future risk intervention programs aimed at teens, and consider directions for future research.

Adult Decision Making and the Description-Experience Gap

JDM studies have extensively investigated decision making and risk taking in the context of varying modes of information acquisition. Historically, JDM studies have asked participants to make risky decisions based on explicit descriptions of the probabilities and associated costs (these paradigms have come to be referred to as Decisions from Description, or DFD, paradigms). For example, participants may be given a choice between gaining \$4 for sure, or taking a risk with an 90% chance of gaining \$6 but a 10% chance of losing \$1. While this simple type of problem may not seem immediately relevant to the sort of decision making that takes place in daily life, one can equate the problem to a real-life choice in which taking a risk confers a high probability of a favorable outcome and a low probability of an unfavorable outcome. For example, most of the time, driving above the speed limit allows one to reach the destination sooner, but in rare cases, can lead to a speeding ticket (or worse).

Cumulative Prospect Theory (CPT; Tversky & Kahneman, 1992), a highly influential model of decision making in DFD (de Palma et al., 2014), predicts that people will typically be risk-averse when faced with high probability favorable outcomes and low probability unfavorable outcomes, but risk-seeking when faced with low probability favorable outcomes and high probability unfavorable outcomes (Tversky & Kahneman, 1992). In the context of the aforementioned decision problem, CPT predicts that participants will tend to overweight the rare likelihood of the \$1 loss outcome, leading the majority to be risk-averse and select the safe alternative (Hertwig, Barron, Weber, & Erev, 2004).

Although CPT has some shortcomings (see e.g., Kühberger & Tanner, 2009; Reyna, Chick, Corbin, & Hsia, 2014), it remains a predominant model in understanding DFD behavior. In DFD paradigms, participants have full knowledge of the decision alternatives before making a decision. Yet, it is important to point out that humans rarely make choices where they precisely incorporate the exact probabilities of all possible outcomes of a choice (Simon, 1955). Rather, real-world decision making is often based at least in part on information obtained from past experiences in the same or similar contexts. In a seminal paper, Hertwig and colleagues (2004) directly contrasted behavioral patterns elicited during DFD, to those observed in a different class of paradigms, Decisions from Experience (DFE)¹. In DFE paradigms, which may more closely mimic information gathering as it occurs in many real-

¹Decisions from Experience paradigms were not themselves new, but were derived from other probability learning paradigms that were common in the mid-20th century (e.g., Estes & Branch, 1964; for review, see Luce & Suppes, 1965). The novel theoretical claim in Hertwig and colleagues (2004) is the distinction between DFD and DFE (Wulff et al., 2017).

world situations, (Barron & Erev, 2003; Hertwig et al., 2004; Weber, Shafir, & Blais, 2004), participants must actively acquire information about the possible outcomes by repeatedly sampling the alternatives and observing the decision outcomes (i.e., by accumulating personal experience). Surprisingly, in DFE paradigms, the pattern of decision preferences is generally opposite to that predicted by CPT: participants tend to make decisions consistent with the underweighting of rare outcomes (Hertwig et al., 2004). In the lottery example above, this would translate to choosing the risky option over the safe option (i.e., underweighting the chance of the \$1 loss outcome and taking a risk in hopes of gaining \$6, rather than taking the sure \$4). Interestingly, this flipped pattern resembles many behaviors observed in everyday decision making. To return to the speeding example, speeding is an exceptionally common behavior, which suggests that drivers tend to overweight the likelihood of the higher probability outcome (reaching the destination more quickly) and underweight the likelihood of the rare outcome (a speeding ticket; Camilleri & Newell, 2011a) – a pattern opposite to that predicted by CPT².

A large number of recent studies have explicitly demonstrated the difference in behavior that occurs between described and experienced decision problems (for reviews, see Camilleri & Newell, 2013; de Palma et al., 2014; Wulff, Mergenthaler-Canseco, & Hertwig, 2017). The disparate choices of those in a DFD group compared to those in a DFE group is known as the Description-Experience gap (D-E gap; Hertwig et al., 2004). While the D-E gap is generally robust, there is some debate about its cause and most appropriate interpretation. For instance, in some cases, participants do not experience (or sample) every possible outcome in the distribution, especially when one outcome is particularly rare (very low probability; Fox & Hadar, 2006; Hau, Pleskac, Kiefer, & Hertwig, 2008). In fact, in a follow-up analysis of data from Hertwig and colleagues (2004), Fox and Hadar (2006) found that the D-E gap could be fully accounted for by the “sampling error” that arises when one’s experiences misrepresent the true underlying probabilities. Some subsequent experimental manipulations aimed at eliminating sampling error have, indeed, also eliminated the D-E gap (Camilleri & Newell, 2011a; Hadar & Fox, 2009; Rakow, Demes, & Newell, 2008). However, a number of other studies have found that the D-E gap remains significant, though diminished, after accounting for sampling error (Camilleri & Newell, 2011b; Hau, Pleskac, & Hertwig, 2010; Hau et al., 2008), and a very recent meta-analysis by Wulff and colleagues (2017) found that overall, the D-E gap is not fully eliminated by controlling for sampling bias.

Researchers have also interpreted the D-E gap with respect to memory limitations (Camilleri & Newell, 2013). In the DFE condition, the extended history of outcomes must be maintained and accessed from memory in order to guide subsequent decision making. Since more recent information tends to be more easily accessed and retrieved, participants may exhibit a “recency bias” in which more recently presented outcomes have a relatively greater influence on decision making (Barron & Yechiam, 2009; Hertwig et al., 2004; Rakow et al.,

²It is important to note that sometimes this bias for underweighting rare events can only be considered as underweighting when it is considered relative to behavior in description-based choices. A recent metaanalysis (Wulff et al., 2017) found that in problems with one risky and one safe outcome (the most common type of decision problem in sampling paradigms), participants in DFE make choices suggesting they weight outcomes accurately according to their underlying probability distributions.

2008). However, the D-E gap has been found to persist (albeit in a potentially reduced form) even when the order of outcomes is experimentally controlled to account for recency effects, and when participants are given an exact record of the entire sampling history (so that this history is fully accessible at the time of decision making; Camilleri & Newell, 2011a; Gottlieb, Weiss, & Chapman, 2007; Hau et al., 2010). Moreover, meta-analysis indicates that recency effects arise mostly when sampling is autonomous (i.e., when the participant is able to choose when to stop search), and does not typically arise when the experiment requires participants to complete a fixed (or minimum) number samples (Wulff et al., 2017). Thus, while both sampling error and recency bias likely contribute to the D-E gap, the D-E gap is observed even when these factors are taken into account.

Description Plus Experience

Although the JDM field has focused considerable attention on the distinction between decisions made from description (DFD) and those made from experience (DFE), there are many instances in life when people have access to both descriptive information and information derived from prior experiences. For example, a doctor may acquire information about the likelihood of a patient having a disease, given a certain pattern of symptoms, both from a textbook description and from her own experience from seeing patients with similar symptoms in the past. The blending of described and experienced information may likewise be prevalent in adolescent risk taking, as adolescents may have both personal experience with some types of risky behavior, and descriptive information (perhaps acquired in the classroom) about the dangers of that behavior. Understanding how described and experienced information interact may be especially important in developing more-effective risk interventions.

To assess how decision making might vary based on the availability of both descriptive and experienced information, a few studies have deployed a paradigm in which participants are asked to make repeated decisions from description either with, or without, experiential feedback regarding the outcomes of those choices. Jessup, Bishara and Busemeyer (2008), for instance, compared patterns of choice when participants were asked to make repeated decisions from description with feedback (i.e., the outcome of the chosen option was revealed) vs. without any feedback. They found that participants who received feedback underweighted rare outcomes relative to those in the no-feedback group. That is, those who received feedback behaved the way participants in a standard DFE paradigm (experience only) tend to behave, even though they were also provided with full descriptive information. A study by Lejarraga and Gonzalez (2011) built upon the study by Jessup and colleagues (2008) by examining behavior in experience-only (with feedback), description-only, and description plus experience (repeated feedback with descriptions) conditions in a lottery game. They found that participants in the description plus experience condition behaved more like those in the experience-only condition than those in the description-only condition. Put together, these studies indicate that in paradigms with repeated decisions from description with feedback (i.e., experience), participants tend to weight the experienced information more heavily over time, leading to underweighting of rare outcomes (Yechiam, Barron, & Erev, 2005). Interestingly, Yechiam and Busemeyer (2006) found that this pattern can be further exaggerated when information about the foregone outcome is also provided.

(When feedback on both the chosen and foregone outcomes is provided, this is referred to as “full feedback,” as opposed to “partial feedback” when only the chosen outcome is shown).

Other relevant work has explored the relative timing of descriptive and experienced information and the differential impact on choice behavior. In naturalistic settings, descriptive information may not always precede experience. One study addressed this issue by varying, relative to the opportunity to engage in experience sampling, the timing of descriptive information in the form of a “warning” about the possibility of a rare negative outcome (Barron, Leider, & Stack, 2008). Participants were given a warning about the possibility of a \$15 loss (which occurred with a probability of only .001, so it was rarely experienced) either “early,” before experience sampling began, or “late,” after half of their sampling decisions had been made. Those who received an early warning took fewer risks compared to those who received a late warning, and the late warning was not enough to prevent participants from underweighting the rare negative outcome. This continued underweighting of the rare event after a late warning was even more pronounced when participants received full feedback after every sampling decision, perhaps again due to the emphasis on the rarity of the unlikely outcome.

Putting the findings together, there seems to be something psychologically different about repeatedly experiencing outcomes from decision alternatives, and this leads to different choices compared to circumstances in which decision alternatives and their consequences are merely described. The ability of experience-based information to outweigh description in experimental paradigms, and the parallels between experimental experience-based paradigms and naturalistic contexts that involve repeated decisions provide key insights that can inform our understanding of risk behavior during adolescence.

Linking the Adult D-E Gap Literature with Developmental Studies of Risky Choice

As discussed earlier, teens are known to take more risks than adults in many real-world contexts. While there is a large literature exploring the specific developmental mechanisms that might explain this phenomenon, there has, for the most part, been a disconnect between the JDM literature and examinations (both empirical and theoretical) of age differences in risk taking (Hartley & Somerville, 2015). A notable exception is work grounded in fuzzy-trace theory, which applies a framework motivated by JDM research to account for developmental changes in risk behavior (Rivers et al., 2008). According to this model, experience and maturation together lead to a decreasing use of verbatim mental representations during decision episodes, and an increasing reliance on intuitive, gist-based, representations. While recent findings regarding the D-E gap (in the adult JDM literature) may be interpreted within the theoretical framework of fuzzy-trace theory, a point to which we will return to later, the specific question of whether descriptions and experiences differentially affect *adolescent* decision making has gone almost entirely unexplored. Accordingly, the remainder of this article focuses on a rich literature surrounding adolescent decision making, but re-examined through the lens of prior work on the adult D-E gap. In particular, we examine how adolescent decision making varies when the information that

guides it has been acquired via descriptions versus experience. In this reevaluation of the adolescent risk-taking literature, we explore whether the prevailing influence of experience over description is observed, and perhaps amplified, among teens as it has been among adults.

Based on both experimental and epidemiological data, there is reason to believe that adolescents may actually exhibit a larger D-E gap than do adults. For example, adolescents have more difficulty than adults in updating their beliefs after being given explicit instruction about risk likelihood (Moutsiana et al., 2013). Moreover, we know that teens engage in heightened risk taking even in situations where they clearly possess descriptive knowledge of the risks involved, and even when that descriptive knowledge overestimates the true likelihood of negative outcomes (an effect attributed to a cost-benefit analysis between very likely rewards and unlikely consequences; Reyna & Farley, 2006). Perhaps the impact of ones' own experiences, even in the face of factual information, is more salient during adolescence and thus overshadows descriptions, making these described risk probabilities more difficult to learn (Albert & Steinberg, 2011; similar to results in studies investigating repeated DFD, Jessup et al., 2008).

To date, three studies directly or indirectly test both DFD and DFE problems in adolescents and adults. The first study (Rakow & Rahim, 2010) presented three experiments testing the D-E gap across different age cohorts: 1) children vs. adults, 2) children vs. adolescents, and 3) younger adolescents vs. older adolescents. Due to the wide age range of participants in the study, the authors used a child-friendly DFE task, in which participants drew colored cubes from boxes rather than sampling numbers from "Point Machines" or "Money Machines," as the task is generally implemented in adult-only samples. Each color cube represented a different point value. Participants were required to sample from each box 10 times (with replacement) before making a final decision about which box they preferred. They also completed the DFD paradigm, where the values and numbers of each color cube were explicitly described as a frequency (e.g., this box has 9 red cubes worth 10 points each and 1 blue cube worth 0 points). In the child vs. adult and child vs. adolescent experiments, DFD and DFE conditions were presented between subjects, while in the younger vs. older adolescent experiment, DFD and DFE were both presented to the same participants in counterbalanced order.

The authors found a D-E gap in adolescents and in children, although the size and significance of the gap varied greatly across problems and across the three experiments (Rakow & Rahim, 2010). However, the study found no significant difference in the overall D-E gap when directly comparing younger versus older groups, for any of their developmental comparisons.

When interpreting these results, it is important to consider some limitations of the study. Foremost, in the experiment that compared adults to children, the overall D-E gap was not significant among the adults, which is noteworthy given that most experiments using similar paradigms find a robust D-E gap in adult samples. The null result may have been due to the use of a modified paradigm requiring a small number of fixed samples from each alternative (which also led to a null result in Hadar & Fox, 2009). Additionally, whereas our present

interest is in directly contrasting a D-E gap in adolescents to that in adults, the methods employed in Rakow and Rahim's (2010) study precluded a direct comparison of behavior between the adolescent and adult participants, as these two age groups were never directly paired in any of the experiments, and the authors employed a different set of decision problems within each of their three experiments. Moreover, the adult D-E gap was examined in a between-subjects design, whereas that for adolescents was tested using a within-subjects design. Thus, although important for having demonstrated, for the first time, the presence of a D-E gap in an adolescent sample, Rakow and Rahim's (2010) investigation provides no direct evidence regarding how the use of descriptive and experienced information might differ between adolescence and adulthood.

A more recent study by van Duijvenvoorde and colleagues (van Duijvenvoorde, Jansen, Bredman, & Huizenga, 2012) provides further insight into how adolescents might differentially respond to descriptive and experience-based information, and provides a direct comparison to an adult group. This study did not employ standard DFD or DFE paradigms, but rather, had participants play a modified Iowa Gambling Task (IGT; the original version of this task, and some limitations of this task in particular, is discussed in greater detail below). In the task, participants were asked to choose which of four different machines they wished to play. Two of the machines were "good" and provided subjects with smaller gains coupled with smaller and/or less frequent losses, such that the expected value (EV) of both machines was positive. The other two machines were "bad" and yielded higher gains coupled with larger and/or more frequent losses, giving them negative EVs. In an *informed* condition, participants were shown the true underlying probability distributions in a graphic form, making this condition akin to a DFD paradigm. In the *uninformed* condition, participants needed to learn the probability distributions by trying each machine, similar to a DFE paradigm. This study included participants aged 7 to 29, and many of the analyses focused on differences across the spectrum of development rather than on a contrast between specific age groups (e.g., adolescents vs. adults). However, careful examination of the figures in the paper suggests that in the informed (DFD-like) condition, adolescents performed more similarly to adults than in the uninformed (DFE-like) condition (van Duijvenvoorde et al., 2012). In thinking about how risk is defined in behavioral economics – the pursuit of the alternative with the highest outcome variance (i.e., largest variance around the expected value; Weber, Shafir, & Blais, 2004) – choices from the "bad" machine with the highest outcome variance are of particular interest (Schonberg, Fox, & Poldrack, 2011). In the last 60 trials, adolescents chose this specifically riskier machine less often than chance only in the informed, but not in the uninformed, condition. This pattern is consistent with the notion that age-related differences may be less apparent in tasks that emphasize descriptive information, than in those in which participants' choices are more influenced by prior (or accumulating) experience.

Last, a very recent study tested both DFD and DFE in participants ages 9 to 22 (van den Bos & Hertwig, 2017). Like van Duijvenvoorde et al. (2012), this study used continuous age measures without directly contrasting adolescent to adult behavior. Interestingly, the authors found a quadratic relationship between risk-taking and age for DFD in the gain domain, such that adolescents showed more risk taking than younger or older individuals. In loss

problems, there was a linear decrease in risk taking across age groups, with adolescents displaying intermediate risk taking between children and adults.

The van den Bos and Hertwig (2017) study did not report risk-taking behaviors within DFE by age group. However, the authors reported data in the supplemental materials showing a quadratic pattern in the magnitude of the D-E gap as a function of age for problems in which the rare event was unfavorable, translating to heightened risk taking in adolescents in this type of problem. This pattern persisted, even after accounting for sampling bias. Such heightened underweighting of rare events in DFE maps onto teens' dangerous risk taking behaviors in the real world. For instance, when adolescents choose to use drugs, despite the rare possibility of overdose (a rare unfavorable outcome), they are behaving as if they underweight the overdose outcome. The intriguing parallels between DFE risk behavior and adolescents' heightened real-world risk taking hints that DFE (and contrasts between DFD and DFE; i.e., the D-E Gap) may be a fruitful paradigm to use in understanding adolescent risk behavior.

In developing a theoretical account of the D-E gap among adolescents, it is important to bear in mind the possible contributions of sampling bias and memory-related effects (e.g., recency); two factors that have been shown to affect the size of the D-E gap in adults. Indeed, related evidence suggests that adolescents might be more prone to both of these effects than are adults. Adolescents, for instance, are known to be more impulsive than adults (Luna, Garver, Urban, Lazar, & Sweeney, 2004; Shulman, Smith, et al., 2016; Steinberg, 2008), which could lead them to render decisions after fewer samples in a DFE sampling paradigm. Likewise, developmental differences in memory are important to consider with respect to the D-E gap, since DFE tasks require participants to keep and/or retrieve the previously experienced outcomes in active working memory, in order to inform their final decisions (Camilleri & Newell, 2013), a process that may be affected by age-dependent changes in memory capacity (Jones, 1971; Kareev, 1995, 2000). Accordingly, a relatively immature capacity to access prior sampling experiences from memory could increase bias towards only the more recently presented outcomes that are most accessible. Although some studies indicate near adult-like working memory and brain function in mid-adolescence (Crone, Wendelken, Donohue, van Leijenhorst, & Bunge, 2006), others provide evidence of a more protracted period of development extending into adulthood (Andre, Picchioni, Zhang, & Touloupoulou, 2015; Bunge & Wright, 2007; Jenkins, Myerson, Hale, & Fry, 1999; Luciana et al., 2005). Where links between the developmental status of memory and decision making have been more directly explored, the data suggest that the role of memory is small. Crone and van der Molen (2004), for example, showed that working memory span was not significantly related to performance on the Iowa Gambling Task, an experience-based task. Likewise, in Rakow and Rahim (2010)'s developmental study, a fourth experiment (not discussed earlier) contrasted adolescent and adult participants' memory of a sampling distribution and found that performance on the memory test did not differ significantly between adolescents and adults. So, while developmental differences in both sampling and recency effects should be explored systematically in future studies, these factors do not appear to be critical to the exposition below.

A Review of Developmental Studies of Risky Choice through a Description-Experience Lens

As we note above, very little research has been conducted in developmental samples using the traditional DFD and DFE paradigms that form the backbone of work on the D-E gap. There is, however, a relatively large literature comparing adolescents' propensity for risky decision making to that of adults. In this section we revisit this corpus of work while taking into account the distinction between decisions made from description and those made from experience. Specifically, we consider whether the observation of age differences in a given study depends on the type (description or experience) of paradigm that was used. We acknowledge that such a post-hoc classification of existing work along a description/experience axis may be confounded by differences between studies with regard to other factors like memory, attention, learning, and estimation of expected values; we address the topic of confounding factors in the discussion.

A recent meta-analysis (Defoe, Dubas, Figner, & Van Aken, 2015) provides some initial grounding on this issue. The authors examined laboratory risk-taking from childhood to adulthood and determined that, as expected, adolescent risk-taking in laboratory tasks is overall significantly elevated relative to adult risk-taking, despite a few individual studies that do not show this age-related difference. The authors also found that this age difference in risk taking is accentuated in tasks providing immediate, relative to delayed, feedback about decision outcomes, although this moderator was only marginally significant. In their investigation, Defoe and colleagues (2015) also acknowledged the importance of the description versus experience distinction. They discussed how experience-based tasks are thought to be more affective, or arousing, in nature (a point also made by Figner, Mackinlay, Wilkening, & Weber, 2009) and noted that this could be important because heightened affect is often a contributor to adolescent risk taking (Steinberg, 2008). In experience-based tasks, heightened affect is likely induced by the tendency to rely more on a "gut" feeling rather than a cognitive calculation (Defoe et al., 2015). Conversely, Defoe and colleagues suggested that description-based tasks are more likely to be associated with non-affective or "cold" contexts, which call upon more deliberative processes (e.g., explicit calculation of expected values; Defoe et al., 2015; Figner et al., 2009). This difference in affect may make description-based tasks less likely to evince developmental differences. Upon consideration of the distinction between description- and experience-based tasks, Defoe and colleagues (2015) made an effort to code studies along these dimensions (though few details are given with respect to how they went about classifying individual tasks). Unfortunately, after applying their eligibility criteria, the authors concluded that there were too few studies in each category (description, experience) to run a moderator analysis.

As we discuss in detail below, through a review of the literature, we find that task format does indeed appear to be a crucial factor in determining whether or not a given study finds age differences in risk taking. Importantly, the present manuscript primarily aims to provide a qualitative analysis of age differences observed within DFD and DFE tasks. We feel that this is appropriate given the great deal of heterogeneity across studies in the characterization of risk taking behavior (as noted by Defoe et al., 2015), and since qualitative review allowed

us to consider several studies that could not be included in formal meta-analysis due to a lack of adequate effect size information. However, in acknowledging that a more formal, quantitative, analysis would also be of interest to readers, and since we were able to identify several studies published since, or overlooked/excluded for other reasons from Defoe et al. (2015), we also conducted a supplemental quantitative effect-size meta-analyses based on a subset of the identified studies. The main findings from the effect size meta-analysis are noted below, and further details are provided in the online supplement to this paper (see Supplemental Information).

To support review of this work, we identified all experiments³ that compared risk taking in adolescents (ages 11–18) to adults (ages 18 and older),⁴ and we then classified them according to whether the task used in the comparison was description- or experience-based. We classified any task that presented full descriptive information to a participant, either graphically or verbally, as a description-based task. Conversely, we classified tasks that did not present descriptive information, but rather required participants to learn about potential decision outcomes through experience in the task as experience-based. Table 1 lists studies included in the resulting analysis. Of note, several of the studies we include in Table 1 were conducted in the fMRI scanner. A discussion of neural differences is beyond the scope of the current review⁵, but Table 1 indicates whether a given study was conducted in the fMRI scanner, and we note that some studies not finding age-related behavior differences do find neural age differences.

Although identifying a given task as description-based or experience-based was relatively straightforward, there was some ambiguity as to what specific behavior constitutes risk taking in certain tasks. This was especially an issue in studies using the IGT (a variant of which was described in the previous section), a widely used experience-based decision-making task. Generally, IGT analysis involves computation of a “net score,” computed as the number of draws from good decks (those offering favorable returns over time) minus the number of draws from bad decks (those offering unfavorable returns over time but with intermittent rewards that can occasionally be large). Since a lower net score indicates relatively increased pursuit of the infrequent rewards provided by the bad decks, the net score itself provides an index of risk taking in this task (with lower net score indicating greater risk taking). Still, as noted by Defoe and colleagues (2015) as well as Schonberg, Fox, and Poldrack (2011), net score is an imperfect index of risk behavior because it does not distinguish between overall approach toward good decks versus avoidance of bad decks (although see Cauffman et al., 2010 and Icenogle et al., 2016 for studies that did make this distinction). Moreover, net score computation conflates sensitivity to expected value with the variance of possible outcomes⁶. In light of these concerns, where possible, we also examined risk taking as indexed by specific choice behavior from the two bad decks, with

³It is important to note that the review includes only studies produced in a search prior to December of 2016. However, we also discuss a particularly relevant study published in January, 2017 (van den Bos & Hertwig, 2017).

⁴Some of the studies include 18-year-olds in the adolescent group, while others include 18-year-olds in the adult group. See Table 1 for age ranges in all included studies.

⁵As is apparent in Table 1, whether a study was conducted in the scanner does not appear to affect the presence or absence of a developmental difference (2 of 3 DFE studies and 2 of 7 DFD studies showed a developmental difference in the scanner)

⁶Similar criticisms have been raised of the Balloon Analog Risk Task (BART) and its variants, as discussed below where we elaborate on DFE tasks.

higher risk taking indicated by increased selection of the one bad deck that has the greatest variance in possible outcomes (Schonberg et al., 2011; Weber et al., 2004).

Another difficulty we encountered was deciding what constitutes adequate evidence of greater risk taking in the comparison of adolescents to adults. For instance, some studies included multiple adolescent groups (e.g., younger and older adolescents) and reported a difference between younger teens and adults, but not between older teens and adults. For the purposes of the present analysis, if the authors reported that *any* of the adolescent groups took significantly more risks than the adult group in the sample, we classified the study as identifying a developmental difference, but were careful to indicate any caveats in the Table 1 notes. Further, some studies found a developmental difference under certain risk conditions but not others (e.g., a difference when rewards were very high, but not when they were moderate or low; e.g., Reyna et al., 2011). If the authors reported a significant developmental difference in risk taking in any condition in the study, we indicated that a difference was present, but we again note variation in condition effects as a caveat to the result. These caveats are further detailed and considered in the sections below.

In total, we found 38 published studies, including 41 experiments and comparisons relevant to our review. Nineteen of the studies featured experiments using only a description-based task and 15 featured experiments using only an experience-based task. Additionally, the study we previously discussed by van Duijvenvoorde and colleagues (2012) included two tasks: one experience-based, and one with experience accompanied by description. A further study (Figner et al., 2009) also included two different tasks: one description-based, and one in which description was accompanied by repeated choices (i.e., experience). An additional study used a task involving both descriptions and experience (van Duijvenvoorde et al., 2015). Finally, one further study used both a DFD and DFE task (van den Bos & Hertwig, 2017). We could not directly compare adolescent to adult decision making in Rakow and Rahim's (2010) study, so it was not included. Thus, in total we identified 17 experience-based experiments, 21 description-based experiments, and 3 experiments using description plus experience tasks. For the purposes of quantitative meta-analysis, we also determined that a subset of 15 DFD experiments and 10 DFE experiments reported data needed for effect-size estimation (see *Supplemental Table 1*).

As is readily apparent from Table 1, experience-based tasks were more likely to show an age-dependent difference in risk taking relative to description-based tasks. Fifteen out of the 17 experience studies showed an age-dependent difference in risk taking, such that adolescents took more risks than adults (at least for certain comparisons). In contrast, only 8 of the 21 description studies reported an age-dependent difference. Therefore, experience studies are 2.3 times more likely to show age-related differences, which translates to a tenfold increase in the odds of finding significant age differences in experience-based relative to description-based tasks. This difference was also readily evident in quantitative meta-analysis, which confirmed that experience-based tasks (weighted mean effect-size = 0.59) produced significantly larger age differences than did description-based tasks (weighted mean effect-size = 0.18), among studies supporting effect-size estimation ($p < .005$). Of the three D+E studies, one of them showed a clear age-related difference in the expected direction, while in the other two, no difference was apparent.

This overall pattern of choices suggests that DFE paradigms are more likely to reveal developmental differences in risk taking than DFD paradigms. While this overall pattern is compelling, we consider below the specific tasks and methods that are employed in this literature in an effort to illuminate the factors that are most closely associated with the developmental pattern, and elaborate upon studies that showed more definitive developmental differences. If a task was used in multiple studies, we also focus on the consistency of results across those studies.

Experience-Based Decisions

Iowa Gambling Task and its Variants—There were several variants of the IGT across the studies examined. Crone and van der Molen (2004) developed the Hungry Donkey Task, a child-friendly version, in which participants needed to open doors (rather than flip decks) to try to gain apples to feed a hungry donkey (rather than accumulating points or money). Another variant, the Soochow Gambling Task, was developed to equate gain and loss frequency across the good and bad decks (Aite et al., 2012). As discussed above, when net score was reported in the study, we considered a lower net score to be indicative of higher risk taking. Interestingly, 8 out of 9 studies that employed an IGT variant showed a lower net score (i.e., higher risk taking) in teens compared to adults. Thus, despite the slight variation in tasks, results of studies using the IGT (including those from van Duijvenvoorde et al., 2012) are generally consistent with the idea that teens engage in more risk taking than adults.

As mentioned above, it is of interest to examine studies in which it is possible to isolate choices for the bad deck with the highest outcome variability. Six of the 9 IGT studies reported results such that choices for this “risky” deck could be uniquely determined, a behavior that, again, provides an alternate index of risk taking. In Cauffman et al. (2010), choices of both bad decks were inversely related to age, but this relationship was stronger for the deck with higher outcome variability. Van Duijvenvoorde and colleagues (2012) found a similar pattern in their uninformed (i.e., traditional IGT) condition, with adolescents (but not adults) failing to learn to avoid the higher variability bad deck by the last block of the task. Likewise, both Overman and colleagues (2004) and Cassotti and colleagues (2011) found that adolescents chose bad decks with higher outcome variability more often than did adults. Another study (Beitz et al., 2014) found a significant decline in preference for the deck with higher variability from adolescence into adulthood. Only one study obtained results inconsistent with this pattern: in the Soochow Gambling Task, Aite et al. (2012) found a lower net score in adolescents than adults, but this effect was driven by more choices from the deck with *low* rather than high outcome variability.

The Cauffman and colleagues (2010) study used a particular modification of the IGT that sheds further light on these patterns. In their task, the computer highlighted one of the four decks and participants indicated whether they wanted to “Play” from the deck and draw a card, or “Pass” on the deck and not draw a card. This modification allowed a distinction to be made between approaching good decks and avoiding bad decks. The authors found that teens 14–17 years old learned to approach good decks more quickly than adults but were slower to learn to avoid bad decks. This finding is interesting, because in this study the net

score in 14–17 year olds did not significantly differ from that in older individuals. So, it seems that the increased reward approach compensated for the increased plays from bad decks. In that same study, there was a significant difference in net score in 10–13 year olds compared to adults (Cauffman et al., 2010). The 10–13 year olds, however, did not differ from adults in their ability to learn to approach good decks, but they were significantly worse at learning to avoid bad decks, causing a lower overall net score, as well as a slower net improvement rate. Therefore, it appears that age-related differences in the IGT (or at least in this variant) reflect heightened reward-seeking behavior, which is thought to play a key role in real-world adolescent risk-taking (Shulman, Smith et al., 2016; Steinberg, 2008). In a recent study by Icenogle et al. (2016), the researchers found that reward-seeking behavior during the IGT was associated with pubertal maturation, rather than age, which may account for the higher rates of reward-seeking seen among older adolescents than younger ones (adults were not included in this study).

Balloon Analogue Risk Task and Chicken—Another task that is often employed to assess risk taking is the Balloon Analogue Risk Task (BART; Lejuez et al., 2002). In this task, participants are asked to pump a balloon on each trial. Each pump causes an accumulation of money (or points, in a youth version of the task; Lejuez, Aclin, Zvolensky, & Pedulla, 2003). If participants pump a balloon too much and it pops, they lose any accumulated money or points for the balloon. Performance on this task is correlated with self-reported risk-taking in adolescence (Lejuez et al., 2003), and one recent longitudinal study found that adolescents popped more balloons than adults, signifying greater risk taking (Braams, van Duijvenvoorde, Peper, & Crone, 2015). Another study used a variant of the BART, the 2 Balloon Inflation Task (2BIT), which compares risk taking in adolescents to that in adults (Mitchell, Schoel, & Stevens, 2008). In this version, participants held down a button continuously to inflate a balloon and released it to stop inflation when they wanted to cash in for the trial. They gained points for every 60ms the balloon was inflating rather than gaining points for each pump, as in the traditional BART. This study found that teens held the button down longer and popped the balloon more often, and thus exhibited more risk taking than adults (Mitchell et al., 2008).

The Chicken game (Gardner & Steinberg, 2005) is very similar to the BART and the 2BIT variant, in that participants decide when to stop the clock in a given trial (analogous to deciding when to stop inflating a balloon). Delayed responses allow for greater reward accrual, but waiting also increases the likelihood of a negative outcome, which prevents the participant from winning any money for that trial (analogous to the balloon burst in BART). The Chicken game is framed as a driving game, in which participants are asked to make a choice about when to stop a computerized car after a stoplight cycled from green to yellow. At some point after the light turned yellow, a brick wall appeared, which could lead to a crash. Participants were asked to try to drive as far as possible without crashing into the wall, and longer waiting in a trial was associated with more points accumulated. Gardner and Steinberg (2005) also used a social context manipulation, such that participants (adolescents, undergraduates, and adults) either completed the task alone or in the presence of two peers. Results showed both a main effect of age and an interaction between age and social context, such that adolescents always took significantly more risks than older participants, and this

increased risk taking was magnified when peers were present. However, one study using a variant of this task (Bjork, Smith, Danube, & Hommer, 2007) found no difference in risk taking between adolescents and adults. In sum, three of the four chicken or BART variants showed heightened risk taking in adolescents relative to adults, consistent with studies showing the task's ecological validity and ability to predict risk behavior in the real world (Lejuez et al., 2002, 2007; Schonberg et al., 2011).

Simulated driving tasks—Three studies comparing adults and adolescents employed a simulated driving risk game, known as the Stoplight game, as an index of risk taking (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Kim-Spoon et al., 2015; Steinberg et al., 2008). In Stoplight, participants are asked to reach the end of a virtual driving game as quickly as possible. At each intersection they cross, they need to decide whether to stop at a yellow light or proceed into the intersection, an option that may help in reaching the end sooner, but that comes with the risk of crashing. This task is best characterized as experience-based, because participants are not explicitly told the likelihood of crashing if they run the light; they must learn about this likelihood through experience with the task. All three studies showed increased risk taking in teenagers relative to adults. However, in one of these studies, a developmental difference in risk taking only emerged when social context was manipulated, such that adolescents only took more risks when peers were watching, whereas adults were not sensitive to social context (Chein et al., 2011). The absence of a simple main effect of age in that study may reflect a power limitation, and indeed, studies with larger samples find a significant age effect in proportion of lights run (Kim-Spoon et al., 2015, Steinberg, 2015). In sum, as with the IGT, data from studies using the Stoplight task seem to reflect real-world developmental differences in risk taking found within the laboratory, with adolescents taking more risks than adults. Interestingly, Stoplight performance has been related to self-reported sensation seeking (Steinberg et al., 2008), and real world risk taking in adolescents, but not adults (Kim-Spoon et al., 2015). Therefore, the Stoplight game may be a particularly useful task for relating laboratory risk taking to real-world behaviors.

Description-Based Decisions

Paradigms that involve decisions from description in the adolescent decision making literature are generally very similar to one another in their parameters and implementation. Most such studies ask participants to make decisions based on probability information expressed graphically, most often in the form of a pie chart or "wheel of fortune." Some of the tasks involve a decision between two gambles, and others involve choices between a risky and a safe option. Sometimes the choice between a risky and a safe option is in the form of a play or pass decision, in which a decision to pass incurs either no gain or a consistent gain. As was stated earlier, less than half (8 out of 21) of the description studies find a difference in risk taking between teens and adults. Further, 6 of these 8 studies only show the difference in certain trial types or conditions, as we discuss next.

Developmental differences in description tasks—In a study by Burnett and colleagues (Burnett, Bault, Coricelli, & Blakemore, 2010), children (ages 9–11), young adolescents (ages 12–15), mid-adolescents (ages 15–18) and adults (ages 25–35) made decisions between two risky wheels, each of which had a gain outcome and a loss outcome.

Risk taking was conceptualized as choosing the wheel with the highest outcome variance. The authors found a quadratic age trend in risk taking, with risk taking highest in the young adolescent group. The difference between young adolescent and adult risk taking was significant, but the risk-taking difference between mid-adolescents and adults was not (Burnett et al., 2010). Two other studies used similar gambling tasks (Habib et al., 2012, 2015). Interestingly, neither of these studies showed an age difference in risk taking, but both reported a developmental difference in emotional experience in response to feedback across age.

Two description-based studies used variants of the Cups Task, (Galván & McGlennen, 2012; Levin, Bossard, Gaeth, & Yan, 2014), in which participants were asked to choose between safe and risky outcomes. If they chose the safe option, they had a 100% chance of winning or losing a constant described amount of money (e.g., always winning or losing one quarter). The risky option contained 2, 3 or 5 cups, which represented 50%, 33% or 20% chances of winning or losing money, respectively, (always more than the safe option) hidden under one of the cups. Galván and McGlennen (2012) did not find any age differences in risk taking in this task. In contrast, Levin and colleagues (2014) found significantly higher risk taking in adolescents than adults, particularly in gain trials. Interestingly, the authors also investigated whether sensitivity to the EV of the risky option changed developmentally, as indexed by risk taking when the risky option was advantageous vs. when it was disadvantageous. Adults were slightly more sensitive to EV than adolescents, but this difference failed to reach significance.

Two other description studies employed a non-symbolic economic decision making task (Paulsen, Carter, Platt, Huettel, & Brannon, 2012; Paulsen, Platt, Huettel, & Brannon, 2011). In Paulsen et al. (2011), participants decided between two 50/50 risks (risk-risk trials) or between a 50/50 risk and a safe option (risk-safe trials) with the same EV. While EV of the relative alternatives was held constant, the authors varied the decision outcomes such that some problems had larger variability between possible outcomes (e.g., a gamble with outcomes of 3 and 5 has the same EV as one with outcomes 2 and 6, but the latter is “riskier” because the possible outcomes are farther apart). They found that adolescents’ and adults’ risk taking did not differ on risk-risk trials (i.e., adolescents and adults similarly choose the option with the highest outcome variability). On risk-safe trials, however, adolescents took more risks than adults in trials with medium levels of risk, whereas the difference was not significant in low- or high-risk trials. Paulsen et al. (2012) used the same basic task with only risk-safe trials, but varied risk level across trials. In this study, adolescent and adult behavior did not differ. Thus, results from the two studies using this paradigm were not fully consistent in detecting developmental differences. The authors attributed the absence of age differences in the latter study to unusually high risk taking in adults, which may have been tied to the specific parameters used in constructing the task.

Another paradigm that showed age-dependent differences in decisions from description was the cake gambling task, a child-friendly version of many description-based tasks. Two studies (Van Leijenhorst et al., 2010; Van Leijenhorst, Westenberg, & Crone, 2008) used variants of the task in which participants were presented with six slices of “cake,” divided into two flavors – chocolate and strawberry. The ratio of slices in the two “flavors” varied

across trials (e.g., 4 chocolate and 2 strawberry). The flavor with fewer slices (which was, therefore, less likely to be the gamble outcome) was associated with a higher payout (3, 5, 7 or 9 points [2008 study], or 2, 4, 6, or 8 Euro [2010 study]), while the more likely flavor was always associated with a lower payout (1 point/Euro). Participants bet on one of the two flavors, and if they chose correctly received the associated payout, otherwise nothing. In the 2008 study, there were no differences in adolescents' relative to adults' risk taking. The 2010 study, however, reported a developmental difference in the lowest reward condition, such that when given a choice between a more likely 1 Euro payout and a less likely 2 Euro payout, adults were more likely to bet on the 1 Euro than were teens (i.e., adolescents took more risks than adults only in the lowest reward condition). There was no significant developmental difference at higher risky payout levels. Put together, it seems that this task also shows inconsistent developmental differences. Furthermore, the developmental difference obtained at only the 1 vs. 2 Euro condition in the second study may not be very interesting from the standpoint of real-life risk taking, since adolescents' tendency to engage in more risky behavior than adults is normally linked to real world situations in which the stakes are higher.

In another description study, teens and adults made choices between safe and risky spinners (Reyna et al., 2011). The risky spinners varied according to the likelihood of an unfavorable outcome (1/2, 2/3, 3/4), frame (gain, loss), and reward/punishment level (low, medium, high). Physical money corresponding to the reward that was at stake was placed on the respective spinners (or in the loss manipulation, participants were given the money as an endowment before each trial, which they risked losing). On low and medium levels of reward or punishment, adolescent and adult behavior was generally consistent with predictions derived from Prospect Theory, such that people of both ages were risk seeking for loss problems and risk-averse for gain problems (at these two levels, it appears as if teens might have taken fewer risks than adults, but the authors do not report whether this difference is significant). However, in the high reward/punishment context (when collapsed across outcome ratios), adolescents (but not adults) showed reverse-framing effects: they were more risk seeking for gains than for losses⁷. Interestingly, reverse-framing behavior also predicted individual differences in self-reported sexual risk taking. While many of the description-based results have not shown significant differences in these meaningful conditions, these results from Reyna et al.'s (2011) study are consistent with teens' heightened risk seeking when a large reward is possible.

In a different gambling task, participants made choices between risky and safe options, and all possible outcomes were framed in the gain domain (risky options involved a larger gain than the sure option, otherwise there was no gain, similar to the DFD problems often described in the JDM literature; Engelmann, Moore, Monica Capra, & Berns, 2012). On half of the trials, participants received "expert advice" on which alternative was most advantageous. On some trials, participants were advised to take a risk, while on other trials the expert advised a safe choice. Results indicated that when a gamble would result in a

⁷The authors interpret reverse framing in terms of fuzzy-trace theory, such that teens are engaging verbatim rather than gist-based processing, leading to a cost-benefit analysis, which enhances the attractiveness of the large reward (Reyna et al., 2011). Fuzzy-trace theory is addressed further in our discussion below.

likely gain, adolescents were more risk seeking than adults. However, when a gamble presented an unlikely gain, adolescents were actually more risk averse than adults. Further, adolescents became more risk averse for higher-probability gambles when given risk-averse advice, leading teens to decide similarly to adults in the presence of expert advice.

A similar study involved decisions from description with advice, but the advice came from peers rather than experts (Haddad, Harrison, Norman, & Lau, 2014). Participants in this study were shown a “Wheel of Fortune”, with a smaller, less probable section of the wheel tied to a larger possible gain, and a larger, more probable section tied to a smaller gain (as in the cake gambling task). Participants were asked to “bet” on which section the wheel would land when spun once, and a risky decision was defined as a bet on the less probable outcome. The study consisted of four trial types: private, observed (participants were watched by peers, but peers did not give advice), advised risky (peers observed choices and suggested risky choice), and advised safe (peers observed and suggested safe choice). Age differences were only observed at the highest levels of risk and in both observed and advised conditions. Whereas there was a main effect of age on high-risk trials (with adolescents taking more risks than adults), teens did not seem to differ in their risk taking in private compared to peer trials ($M = 40\%$, $SD = 32\%$ risk taking vs. $M = 46\%$, $SD = 36\%$ risk taking, although the authors did not report whether this difference was significant). However, adults numerically suppressed their risk taking in observed ($M = 16\%$, $SD = 26\%$) relative to private ($M = 26\%$, $SD = 33\%$) conditions (once again the significance of this particular difference was not reported), leading to a reported significant difference between teens and adults in the observed condition but not the private condition (Haddad et al., 2014). Interestingly, teens were less likely than adults to take their peers’ advice: they took more risks than adults when peers advised a safe decision, and surprisingly, took fewer risks than adults when their peers advised taking a risk. Even though the age difference in these advised risky trials was opposite to what one might expect, teens indeed took more risks in the advised risky condition than they did when merely observed or alone. This setup and finding is similar to the previously discussed “peer effect” on adolescent risk taking in experience-based driving tasks, such that teens tend to take more risks in the presence of peers than alone (Chein et al., 2011; Gardner & Steinberg, 2005). Additionally, this result is consistent with a more recent study showing that teens take more risks when observed by peers than alone in a similar spinner task, and that the effect was limited to the riskiest trials (although this study did not include an adult sample; Smith, Chein, & Steinberg, 2014).

In sum, as is apparent from Table 1, the majority of studies using description-based tasks do not reveal age differences in risk taking, and accordingly, the average age effect-size from description-based studies is quite modest. Further, when specific tasks have been tested in multiple studies, results have been inconsistent (e.g., Burnett et al., 2010 vs. Habib et al., 2012, 2015; Galván & McGlennen, 2012 vs. Levin et al., 2014; Paulsen et al. 2011 vs. 2012; Van Leijenhorst et al., 2008 vs. 2010). In examining the aggregated results, there is not a clear pattern of task conditions that consistently elicit developmental differences across tasks. For instance, one might hypothesize that only the riskiest trials (e.g., those with the highest variability between outcomes) or those with the largest possible reward are the most likely to elicit heightened risk taking in teens. While Reyna and colleagues (2011) found that adolescents only took more risks than adults when an extremely high reward was possible,

Van Leijenhorst and colleagues' (2010) found a difference only in the *lowest* reward condition. Additionally, in Paulsen and colleagues' (2011) study manipulating the variability between outcomes associated with risk, an age difference was apparent in medium-risk, but not high-risk trials. Thus, it seems that varying the riskiness or reward value of a trial often does not influence risk taking in a predictable way.

While task conditions that change trial-by-trial often seem to be ineffective in eliciting higher risk taking in adolescents in DFD paradigms, there may be other contextual factors that make adolescents more likely to take risks in DFD. For instance, studies that have some components mimicking the inherent properties of DFE (e.g., providing feedback as in van Leijenhorst et al. [2008, 2010] and Paulsen et al. [2011, 2012]) may be more likely to evince age differences. This possibility will be further raised in the discussion.

Description vs. Ambiguity in Adolescents—Tymula and colleagues (2012) explored another interesting task variation, in which participants were asked to make decisions from description between a risky and a sure alternative, or to decide between a sure alternative and an ambiguous alternative for which a subset of the possible outcomes were undefined (results from the description trials, but not the ambiguous trials, were included in our earlier tally of study findings). Contrary to many adolescent risk-taking studies, adolescents took significantly *fewer* risks on the description trials than did adults. Further, adults were relatively ambiguity averse – they opted for the sure rather than the ambiguous alternative – a finding consistent with many JDM studies on ambiguous choices (for a review, see Camerer & Weber, 1992). Adolescents, on the other hand, were significantly more likely than adults to gamble on trials characterized by ambiguity. Two recent studies (Blankenstein, Crone, van den Bos, & van Duijvenvoorde, 2016; van den Bos & Hertwig, 2017) replicated Tymula et al. (2012)'s results, demonstrating higher ambiguity tolerance in adolescents relative to adults (although in Blankenstein et al. [2016] there was not a simple age-dependent pattern in a peer advice condition). Thus, the decisions made under conditions of ambiguity were a better laboratory model of real-world patterns. Indeed, just as in the ambiguous condition, real life decisions are often made when the full range of possible decision outcomes and their precise probabilities are unknown. While not an experience task per se, the ambiguity condition is analogous to DFE in that DFE participants often do not sample the full range of possible outcomes and thus render their choices under ambiguous probabilities (Fox & Hadar, 2006; Hertwig et al., 2004). Following this evidence, one may theorize that adolescents' heightened risk taking is not driven by a tolerance for risk, but rather by tolerance for ambiguity, or their acceptance of situations in which all outcomes are not known or cannot be known (van den Bos & Hertwig, 2017). Indeed, van den Bos and Hertwig (2017) showed that adolescents are both more tolerant to uncertainty and to ambiguity. In sum, it seems that decisions under ambiguity and uncertainty (DFE) may be similarly relevant to adolescent risk taking. The nature of the relationship between choices from uncertainty and ambiguity is an interesting topic for examination in future studies.

Description vs. Description + Experience

Hot and Cold Columbia Card Tasks—The Columbia Card Task (CCT) was designed to address some shortcomings of the BART, which is often criticized because it does not allow

for decomposition of the impact of varying decision cues on participant behavior (similar to the IGT, as was discussed above; Figner et al., 2009). Both a “hot” (affective) and a “cold” (non-affective) version of the CCT were developed. In both versions, participants were shown 32 cards face-down and were told that most cards were “gain” cards, which provided a gain of a certain set amount each time one was flipped over. However, there were also a small number of “loss” cards, which led to large losses if encountered. Participants were explicitly told the number of loss cards in a given round, as well as the magnitude of a gain or loss for that round.

In the cold CCT, participants merely declared the number of total cards they would like to flip over for each round. Thus, the cold CCT is a descriptive task, because participants are given full information about the problem’s parameters. They were not given feedback about the result for each draw from the problem’s outcome distribution.

In the hot CCT (Figner et al., 2009; van Duijvenvoorde et al., 2015), participants sequentially flip over cards until they wish to stop and cash in on their earnings for the round. However, if they flip over a loss card, the round ends and any gains for the round are forfeited (and the amount of any losses accrued during the round is deducted from the participant’s previous total). This task is in many ways analogous to repeated DFD tasks in the adult JDM literature. At any given point in time, participants have the requisite probability and gain/loss magnitude information to make a decision about whether to flip over another card or to make the safe choice of stopping. Additionally, like repeated DFD, these repeated decisions with feedback allow participants to directly experience the outcome probability distributions. Thus, the hot CCT combines both DFD and DFE. The main difference between the hot CCT and repeated DFD is that within a given round, the probabilities of win and loss change after each subsequent flip (i.e., the probability of losing increases with each card flip).

In the first study to use the hot and cold versions of the task, Figner and colleagues (2009) found that teens behaved comparably to adults on the cold CCT. However, on the hot CCT, adolescents took significantly more risks than did adults (i.e., they flipped more cards per round). In the context of the present analysis, this result shows that there is no developmental difference in a description task, but a developmental difference emerges when an experiential component is added.

In a more recent study using only the hot CCT, van Duijvenvoorde et al. (2015) used a computational modeling approach to decompose risk-taking behaviors as a function of the riskiness (outcome variability) and EV of the gamble. Interestingly, they did not find a developmental difference in overall risk taking (as determined by the model’s intercept). However, adults were more uniformly risk averse (i.e., they turned over fewer cards when outcome variability was high), while there were more individual differences in response to increasing risk in the adolescent group. The partial inconsistency in findings between the two hot CCT studies parallels that observed in the adult description plus experience literature, where we noted one study failing to find underweighting of rare outcomes in repeated DFD except when full-feedback was provided (Yechiam & Busemeyer, 2006) but

other studies showing that even partial-feedback can produce this characteristic behavior of DFE studies (Jessup et al., 2008; Yechiam et al., 2005).

An Affect-based Model for Risky Choice in Adolescence

Our review of the relevant risky decision-making literature indicates that experience- and description-based laboratory tasks may be differentially effective in exposing age-related differences in risky decision making. In the earlier discussion, we briefly mentioned one possible explanation for this difference – namely, that experience-based decision contexts are more affectively arousing, or “hot”, in nature than are description-based contexts, which may be inherently “cold” (unless some further manipulation of affect is used; Defoe et al., 2015; Figner et al., 2009).

Interestingly, despite widespread use of the term affect in accounts of adolescents’ heightened risk taking, this term is rarely, if ever, explicitly defined. While emotion research has not reached a consensus on the definition of affect (Scherer, 2005), a useful framework comes from Duncan and Barrett (2007), who define the psychological construct as, “a basic, psychologically primitive state that can be described by two psychological properties: hedonic valence (pleasure/displeasure) and arousal (activation/sleepy)” (p. 1185). While not explicitly stated, discussions of affect as it relates to adolescent risk taking usually refer to elevated arousal or activation (independent of valence), and this is how we define affect in the discussion that follows. Much of the developmental research conducted to date focuses on risk taking in relation to reward opportunity, and hence, in positively valenced conditions, but the specific role of positive vs. negative valence in adolescents’ propensity to take risks is a question that has received scant attention (c.f. Cohen et al., 2016; Ernst, 2014).

In order to understand the importance of the distinction between affective and non-affective contexts in adolescence, it is informative to turn to theoretical accounts of adolescent risky decision making. The dual systems model (as well as several similar models; see Shulman, Smith et al., 2016) suggests that adolescent risk taking stems from an imbalance between the development of affective brain circuitry that matures earlier, and shows heightened responsivity during adolescence, and a cognitive control system that undergoes a more prolonged and gradual period of maturation (Steinberg, 2008). Within this model, teens are more likely to take risks in affective contexts because their affective systems are more reactive than those of adults and because adolescents’ cognitive control systems are still immature. In cold (i.e., non-affective) situations, adolescents make similar decisions to adults because adolescents’ affective systems are less likely to be engaged (or more effectively regulated by cognitive control), and hence less likely to “interfere” with decision outcomes. Thus, research studies guided by this model often try to distinguish between risk taking in affective vs. non-affective laboratory task environments (Albert & Steinberg, 2011; Figner et al., 2009).

There is not a clear consensus in the literature about what constitutes an affective vs. a non-affective task. As discussed above, the IGT typically reveals a developmental difference in risk taking. Consistent with this, many have argued that the IGT, an experience-based task, relies on affective processing (Bechara, Damasio, Tranel, & Damasio, 1997; Damasio,

1996). Evidence for this position comes, for instance, from participants' heightened skin conductance responses (SCRs) before selecting from bad decks, an affective response that appears before they have developed explicit knowledge about which decks are good and bad (Bechara et al., 1997; Wagar & Dixon, 2006)⁸.

Others have made similar claims about experience-based tasks being more affective in nature than descriptive tasks. For example, Ludvig and Spetch (2011) suggested that their repeated choice (experience) paradigm induced a "hot" decision-making context because it provided feedback to participants after every decision. In the adolescent decision-making literature, Figner et al. (2009) explicitly named the version of the CCT that gave feedback the "hot" version, and contrasted this version with a "cold" CCT, which did not provide feedback every round. Following suit, Defoe et al. (2015) extended this argument and claimed that dynamic ("experiential") tasks are by nature more "emotional" because they require learning over time and possibly incline participants to respond more based on feeling than on facts.

This distinction between acting on feeling rather than fact can be related to fuzzy-trace theory, discussed earlier, which distinguishes between choices rendered from verbatim (i.e., acting on literal facts) and gist-based representations (Rivers et al., 2008). As delineated in that view, gist processing involves a simple, often categorical representation, which can incorporate emotion, and that generally leads to risk-averse behavior (e.g., in a choice between a sure win and a risk with a possibility of a larger win but also a possibility of not winning, it is better to choose winning something for sure over maybe winning nothing), while verbatim processing reflects cognitive tradeoffs between perceived cost and benefit that tend to yield more risk-tolerant behavior when benefits exceed costs (Reyna & Rivers, 2008). Importantly, verbatim processing is thought to mature earlier in development than gist processing (which requires more extensive experience), and accordingly, adolescent decision making lies closer to the verbatim processing end of the verbatim-gist continuum. Thus, within this account, when adolescents make risky choices it is because they rely on verbatim representations. Verbatim processing involves cost-benefit calculations about risk probabilities and outcomes. From the perspective of a teenager engaging in such processing, benefits may outweigh the likely costs, leading to a risky choice (Mills, Reyna, & Estrada, 2008; Reyna et al., 2011). Conversely, adults are more reliant on gist processing and thus are less likely to make a risky choice.

Fuzzy-trace theory has proven very useful in explaining many instances of adolescent risk taking (Reyna, Weldon, & McCormick, 2015). However, the implications with respect to the description-experience task distinction are less straightforward than might be expected. In their meta-analysis, Defoe and colleagues (2015) consider fuzzy-trace theory as it relates to the role of heightened affect in adolescents' risk taking. As described above, fuzzy-trace theory suggests that verbatim processing is adolescents' default, which by definition involves the affectively cold calculation of outcome probabilities (Rivers et al, 2008).

⁸It should be noted that the Somatic Marker Hypothesis (Bechara et al., 1997), which supports the idea that IGT behavior is driven by emotion, has been criticized. Specifically, some have shown that healthy participants possess explicit knowledge of the IGT deck contingencies, and have questioned the link between SCRs and risk behavior (for an extensive discussion, see Dunn, Dalgleish, & Lawrence, 2006).

However, the relative immaturity of adolescent memory (Andre, Picchioni, Zhang, & Touloupoulou, 2015; Bunge & Wright, 2007; Jenkins, Myerson, Hale, & Fry, 1999; Luciana et al., 2005; Reyna, 2011) and their reactivity to arousal may disrupt their ability to form and utilize those verbatim representations accurately in the experience condition (Rivers et al., 2008), and thus, it is difficult to form clear predictions from fuzzy-trace theory regarding age differences in experience-based contexts.

The dual systems model, on the other hand, suggests that the mechanism driving adolescents' greater risk taking is heightened activity in affective neural structures (Steinberg, 2008), which is more consistent with the arousing decision-making context (Defoe et al., 2015; Figner et al., 2009). This account further explains why it is possible to increase or reduce developmental differences by making description-based tasks more affectively arousing, or experience-based tasks less so. As we noted earlier, a social context manipulation can evoke age differences when description-based tasks are used – a pattern that arises when participants are observed (Smith et al., 2014) or advised (Haddad et al., 2014) by others. Of course, the peer manipulation may not be the only way to induce heightened affect in an otherwise cold task. For example, we discussed earlier a study by Burnett and colleagues (2010) showing an age difference in risk taking in a descriptive probabilistic gambling task. This study also required participants to rate their emotional responses after receiving decision feedback. It is possible that both decision feedback (a dimension previously shown to promote developmental differences; Defoe et al., 2015) and requiring an emotional rating promoted age differences in a task that would not have shown such a difference otherwise.

Keeping results such as these in mind, we propose a basic model, the Spectrum of Affect model, that integrates recent hypotheses about affective arousal during risk taking (Defoe et al., 2015; Figner et al., 2009; Hartley & Somerville, 2015) with the ideas about DFD and DFE explicated in greater depth above. Specifically, we propose that there may be a spectrum of affective arousal (Figure 1) along which decision-making tasks can be arranged. Tasks that are description-based, without any added affective manipulations, tend to be toward the “cold” end of the spectrum, but can be made “hotter” with additional manipulations. Tasks based on experience are usually relatively hotter by nature because of task features such as feedback, and can also be made hotter with additional manipulations. At a certain point on this spectrum, affect is high enough for a task to elicit a detectable age difference (in the case of experience-based tasks, this may occur even in the absence of further manipulation of affect).

Alternative Explanations

We find an affect-based explanation to be compelling in explaining the disparate findings in description-based tasks relative to experience-based tasks. However, it is important to address possible confounding variables that might account for task-based differences in risk taking.

Expected Value

One potential confounding factor is adolescents' ability, relative to adults', to compute Expected Value (EV). As discussed above, the Iowa Gambling Task (IGT), and particularly the net score measure, has been criticized for its inability to disentangle EV sensitivity from risk taking, as the "bad decks" have lower EV than the "good decks" (Schonberg et al., 2011). Further, van Duijvenvoorde and colleagues (2015) arrived at a similar conclusion based on evidence from the hot CCT (which involves both description and experience): adolescents were less sensitive to EV than adults. Therefore, one might relate adolescents' higher risk taking (relative to adults) to their lower sensitivity to EV, or alternatively, to their inability to compute EV. However, in description-based studies, developmental differences in sensitivity to EV are inconsistent (if they are reported at all). In their description-based study, Barkley-Levenson and Galván (2014) found that adolescents were *more* sensitive to EV than adults, while Burnett and colleagues (2010) found the opposite pattern, and several studies have reported no difference (Barkley-Levenson, Van Leijenhorst, & Galván, 2013; Galván & McGlennen, 2012; Keulers, Stiers, & Jolles, 2011). It is additionally worth noting that in many DFD studies, EV is equated in available alternatives (Haddad et al., 2014; Paulsen et al., 2012, 2011; Reyna et al., 2011). In other DFD studies expected value and risk are confounded, such that the riskier option (i.e., the alternative with the higher outcome variability) also has a lower EV (Eshel, Nelson, Blair, Pine, & Ernst, 2007; Habib et al., 2012, 2015). Future studies should clarify the relative impact of EV sensitivity on developmental differences in risk.

Risk Taking versus Sensation Seeking

While the present review focused on the *behavioral outcomes* (i.e., the risky behaviors observed in the lab or real world) reported across studies, we would ideally be able to more directly assess the *psychological states* that motivate, or drive, these behaviors (Shulman, Smith et al., 2016). This distinction is important because meaningful developmental differences in the drive to pursue risks may be present even when no behavioral differences emerge, such as when the opportunity to enact the behavior is limited by the experimental task or by real-world constraints on behavior. Dual systems explanations suggest that adolescents' greater inclination toward reward seeking and sensation seeking may underlie their risk seeking. Unfortunately, most of the present studies confound risk taking with reward and sensation seeking, such that participants must take a risk to receive higher reward (Defoe et al., 2015). How these constructs relate to decisions from description vs. experience remains to be studied. It is possible, for example, that the arousing context of an experience-based decision heightens adolescents' drive to seek rewards, while the less arousing description-based context has the opposite effect. In this way, what emerges as differences in risk behavior are really driven by differences in reward sensitivity.

Attention/Task Engagement

A further alternative account to the framework proposed here is one that is based on differences in attention and task engagement. For example, one could argue that experience-based tasks are simply more exciting relative to description-based tasks, leading to differential levels of engagement across these tasks among adolescents, and accounting for

differences in risk taking (i.e., more risk taking on more exciting tasks). Indeed, it is plausible that merely having heightened attention to a risk-taking task might lead to more risk behavior. However, the opposite prediction is also plausible, as higher affect is linked to impulsivity, which is often associated with reduced attention (e.g., individuals with ADHD, who have low attention, often show higher task-based arousal; Bjork & Pardini, 2014; Elkins, McGue, & Iacono, 2007). Future studies can help delineate the precise roles of arousal vs. attention/task engagement by careful examination of behavioral results (e.g., decision latency, sampling behavior, etc.), or through the use of eye tracking, neurophysiological measures, and self-reports of emotional states.

Probability Weighting

The Spectrum of Affect model can be used to make developmental predictions about overall risk taking in DFE relative to DFD. However, the traditional D-E gap paradigm deviates from most of the developmental paradigms that directly motivated the Spectrum of Affect model. In particular, the standard D-E gap paradigm indexes relative biases in *weighting* of outcomes by decision context (overweighting rare outcomes in DFD, and underweighting rare outcomes in DFE; Hertwig et al., 2004). Crucially, D-E gap paradigms typically contain some decision problems with rare favorable outcomes, and some with rare unfavorable outcomes. According to predicted weighting patterns, participants should make a safe choice when the rare outcome is favorable in DFE or when it is unfavorable in DFD.

Developmental DFE risk taking tasks, in contrast to D-E gap paradigms, often only contain problems with unfavorable rare outcomes (if a rare outcome exists at all; often risky alternatives involve two equally probable outcomes). For example, in the IGT, risk taking behavior (in Table 1, quantified as a lower net score, or more draws from bad decks than the good decks) is associated with seeking a more common and higher reward relative to that available in the good decks, with the possibility of an unlikely but larger loss (Bechara, Damasio, Damasio, & Anderson, 1994). According to the predicted pattern, these types of problems in DFE (i.e., with a rare unfavorable outcome) would bias a participant towards risky rather than safe choices. Following this logic, a more pronounced rare-underweighting bias in adolescents (consistent with data in van den Bos and Hertwig, 2017) would produce the pattern of higher risk taking in adolescents relative to adults in DFE observed in Table 1. Consistent with this pattern, adolescents' dangerous risk taking (e.g., drug use) often involve a decision context with a rare unfavorable event (e.g., overdose).

It is unclear whether this systematic rare-underweighting bias would extend to DFE problems with a favorable rare outcome, showing lower risk taking in adolescents versus adults in these problems. An intriguing possibility is that rare outcome underweighting itself could be the mechanism of adolescent risk taking, and this behavioral pattern may be accompanied by heightened affective arousal. In other words, if rare underweighting is the mechanism of heightened risk taking in adolescents, there may not be an overall difference in risk taking if a paradigm systematically tests problems with both favorable and unfavorable rare events.

Although there are few developmental studies systematically exploring the weighting of rare outcomes in DFE, several developmental studies of risk taking have investigated DFD

weighting patterns in adolescents relative to adults (Engelmann et al., 2012; Harbaugh et al., 2002; Tymula et al., 2012). Although the specific weighting tendencies in adolescents differ across these studies (likely due to differences in decision problems, other experimental manipulations, and adolescent/adult age ranges), all three studies showed developmental differences in DFD choice patterns that extended beyond differences in overall risk taking. These results suggest that, while adolescents and adults might have similar mean risk-taking tendencies, decision processes during DFD could differ developmentally. In other words, while adults may take risks consistent with overweighting rare outcomes in DFD, it is possible that adolescents show a less-pronounced rare-overweighting pattern.

An age difference in DFD processing is also interesting from an intervention standpoint. If adolescents do not yet show adult-like biases in outcome weighting, a described intervention message (e.g., using drugs can lead to overdose) might not be perceived or processed in the same way across development. Importantly, this explanation does not necessarily contradict predictions based on the Spectrum of Affect model. Rather, it adds another level of nuance to the model, and may aid in making process-level predictions about developmental differences in DFD relative to DFE.

Conclusions and Future Directions

JDM studies of the D-E gap clearly show that variability in how information about risk is acquired can influence subsequent decision preferences (Hertwig et al., 2004), such that experience-based tasks lead to choices consistent with underweighting of rare outcomes (Camilleri & Newell, 2013; de Palma et al., 2014; Hertwig et al., 2004), an influence that often overpowers that of described information (Barron & Erev, 2003; Barron et al., 2008; Jessup et al., 2008; Lejarraga & Gonzalez, 2011; Yechiam et al., 2005; Yechiam & Busemeyer, 2006). Further, the patterns observed in DFE are, in many cases, more closely aligned with decision making and cognitive processes observed in daily life than those in DFD paradigms (Hertwig et al., 2004).

The distinction between description and experience is especially helpful in making sense of the adolescent risk taking literature. While description and experience tasks are rarely examined within the same sample in the same study of adolescent decision making (Defoe et al., 2015; c.f. Rakow & Rahim, 2010; van den Bos & Hertwig, 2017; van Duijvenvoorde et al., 2012), our analysis of the literature examining developmental differences in risk taking suggests that experience-based tasks do, substantially more often, show developmental differences than do description-based tasks. This pattern is aligned with the idea that teens often make similar decisions to adults in situations that are deliberative and emotionally cold, but make riskier decisions than adults in affective situations more accurately simulated in experience-based tasks (Defoe et al., 2015; Figner et al., 2009). This pattern of age differences holds both in real-life decision scenarios (Albert & Steinberg, 2011; Steinberg, 2008) and in the laboratory (Figner et al., 2009; van Duijvenvoorde et al., 2012).

While this review suggests that DFE may be more likely than DFD paradigms to evince age differences in risk taking, we do not believe that decisions from description always lack utility in developmental studies. Rather, whether description-based tasks are useful depends

on the ultimate hypotheses and goals of a particular study. In studies aiming to advance knowledge about developmental differences in risk taking, experience-based tasks appear to be more sensitive to differences than description-based tasks. However, understanding contexts in which adolescents are able to make adult-like decisions in the real world is also an important goal for research. Researchers looking to further explore the mechanisms that support such decision processes may find that description-based tasks offer a better window into the process of interest.

Additionally, description-based tasks often provide more experimental control than experience-based tasks. The account we present in this paper suggests that description-based tasks may be administered with other affective manipulations (e.g., peer observation) to produce heightened adolescent risk taking in the laboratory. Tasks that involve both description and experience, which are not currently in wide use, could also augment the literature. These tasks may, in fact, be the best laboratory models of adolescent risk taking since they tend to evince similar behavioral patterns to experience-only tasks, but provide full information about the task outcomes. This is akin to adolescents having information about the potential consequences of their actions through interventions, but at the same time possessing experience-based information. In our review, one D+E study showed developmental differences in risk (Figner et al. 2009) and two did not (Van Duijvenvoorde et al., 2012, 2015).

The present analysis also has implications for understanding adolescents' choices in the real world and in implementing interventions designed to discourage adolescent risk taking. Obviously, there is a downside to learning about many risks through experience; a rare but disadvantageous outcome can have serious consequences. However, because experience-based tasks are more likely to evince heightened risk taking in adolescents, they therefore may be more useful in understanding the mechanisms behind adolescents' risk taking through laboratory studies.

Another implication of this review is that interventions based on information alone are unlikely to be effective in deterring the sorts of risk taking for which adolescents' prior experiences have not produced negative outcomes. Indeed, many efforts to reduce adolescent risky decision making focus on instruction-based interventions. As previously mentioned, D.A.R.E., like many other prevention programs, focuses on giving students more knowledge about drugs, often through descriptions of the possible negative outcomes of drug use. Despite its broad adoption and intuitively appealing approach, several large-scale studies indicate that D.A.R.E. has little to no efficacy in preventing drug use in adolescents (Clayton et al., 1996; Ennett et al., 1994; West & O'Neal, 2004; Wysong & Wright, 1995). It is plausible that the lack of efficacy is due, in part, to how adolescents process descriptive information relative to adults.

Interestingly, there have been some promising evidence-based interventions, specifically those targeting sexual risk taking that utilize multi-component approaches (Kirby & Laris, 2009). In a review of 55 sexual risk intervention studies, Kirby and Laris (2009) found that about 2/3 decreased some measure of sexual risk taking. However, the authors mentioned that many of these effects were underpowered, and many studies did not correct for multiple

comparisons. It is also interesting that many interventions for other behaviors (particularly for popular drug abuse interventions such as D.A.R.E.) appear to be less effective (Clayton et al., 1996; Ennett et al., 1994; Singh et al., 2011; West & O'Neal, 2004). While it seems that there is promise in some newer interventions that target multiple health risk behaviors in the same program, a recent review showed that most effects were small (Hale, Fitzgerald-Yau, & Viner, 2014). Thus, there is room for improvement, which may be gained through a better understanding experience-based decision making.

It is important to note, therefore, emerging evidence that virtual reality-based interventions can translate into long-lasting behavioral change in the real world (Ahn, Bailenson, & Park, 2014; Bailey et al., 2015). Accordingly, one might consider attempts to simulate certain risk-taking environments in order to give teens virtual “experiences,” especially negative experiences, with risk taking in a safe, controlled environment. For example, an effective intervention against drinking and driving might use a driving simulator to demonstrate to a teen the difficulty of stopping in time for a red light while intoxicated. Yet another possibility is the use of information-based interventions mainly with younger adolescents, before many of them have had experiences that have not led to negative outcomes. That is, it may be easier to communicate facts about safe sex to a sexually inexperienced 12-year-old than to a 17-year-old who has been having unprotected intercourse for a year but has not experienced a pregnancy or STI.

Future Directions

The existing literature on adolescent decision making is informative in discussing the distinction between description and experience, but future research is necessary to better understand whether and under what circumstances teens' decisions based on described versus experienced information differ. It would be informative to know whether the D-E gap observed in adult samples (using the DFD and DFE paradigms from JDM) is, in fact, evinced in adolescent samples, and, if so, whether it is wider than that observed among adults. Additionally, it would be valuable to test how adolescents respond to manipulations that include both descriptions and experiences.

It would also be helpful to reexamine the literature on differences between adolescent decision making and that of younger individuals from this perspective. Defoe et al. (2015) contended that adolescents and children do not differ in risk taking, and their moderation analysis accounting for description vs. experience tasks did not reach significance. However, it is well known that adolescents take more risks than children in the real world, across many different risk domains. It has been argued that this effect is largely driven by opportunity, and that, given the opportunity to take risks, children will take just as many risks as adolescents (Defoe et al., 2015; Shulman, Smith et al., 2016). Importantly, however, fuzzy-trace theory and dual systems models make different predictions about risk taking in the laboratory across development. Specifically, fuzzy-trace theory generally predicts higher risk taking in children than in adolescents (except when possible gains are very large, when reverse framing is observed; Reyna, et al., 2011). Conversely, the dual systems view predicts the opposite pattern. Notably, neither a dual systems nor fuzzy-trace account predicts that there will be *no* differences between adolescents and children in risk taking. The findings in

the Defoe et al. (2015) of child vs. adolescent decision making (*Figure 2*) are highly heterogeneous, with some studies clearly showing heightened risk taking in adolescents and others showing heightened risk taking in children. Perhaps moderators that are important in explaining developmental differences in risk between children and adolescents have not yet been discovered. Future studies will help to disentangle theoretical differences between fuzzy-trace theory and dual systems model, and to refine these models accordingly.

One shortcoming of our current review involves the comparison of a wide variety of tasks with varying definitions of risk taking (a key reason that we did not take a purely quantitative approach, and a limitation of the meta-analysis completed by Defoe and colleagues, 2015). As research on developmental differences in risk taking progresses, it will be important to directly empirically test the Spectrum of Affect model advanced in this article, using both description- and experience-based tasks within the same study, and adding other manipulations that may increase affective arousal (e.g., offering rewarding feedback). To understand whether affect is, indeed, an important factor in whether a task shows differences between adolescent and adult decision making, we must also measure task-evoked affective arousal as a manipulation check. We acknowledge that this argument may at first seem circular (i.e., when not showing heightened adolescent risk taking, one can always claim that the task was not “affective enough”). However, using physiological tools often used in the emotion literature (e.g., skin conductance, heart rate measurements, pupillometry, EEG; Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2008) will help to clarify situations in which teens show heightened affective arousal. Additionally, self-reported emotional engagement may be a useful tool (e.g., Burnett et al., 2010). fMRI studies of risk taking and activation of relevant affective brain structures may also be relevant, but are more expensive and less direct than the measures mentioned above. We hope that many researchers in the field will begin directly measuring affect and that the field might reach a consensus on what constitutes heightened arousal in an adolescent sample, and on how affect is related to risk-taking tendencies.

Finally, although teens take more risks than adults in general, there is considerable individual variability in risk taking among same-aged adolescents (Bjork & Pardini, 2014). Risk-taking interventions may be most effective if they target those teenagers who are prone to heightened risk taking, rather than those who are unlikely to take risks in the first place. In looking to inform risk-taking interventions that target at-risk teens, it is important to recognize that many of the tasks employed in both the JDM and adolescent risk taking literatures use between-subjects designs, such that each individual participant does not experience all of the experimental manipulations. While this is advantageous from an experimental design standpoint, in ensuring that exposure to one manipulation does not influence performance in the other, these designs cannot help us understand how the same individual might respond to information acquired in different modalities. Therefore, future studies would benefit not only from including both adolescent and adult samples in testing the D-E gap, but by implementing within-subjects designs to improve our understanding of individual differences in risk taking.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

D-E	Description-Experience
DFD	Decisions from Description
DFE	Decisions from Experience
JDM	Judgment and Decision Making

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Highlights

- Adults behave differently when risk problems are described vs. experienced
- This distinction is often ignored in models of teens' risk taking
- Experience-based tasks more reliably evince heightened risk taking in adolescents
- An affect-based model, considering information source, can explain teens' behavior

Figure 1.

Proposed “Spectrum of Affect” – more affective tasks are more likely to show a developmental difference than less affective tasks, and description-based tasks are colder than experience-based tasks.

Table 1

Tasks Discussed in Qualitative Analysis of Adolescent vs. Adult Risk Taking Studies

First author	Year	Task	Description or Experience	Adolescent Ages	Adult Ages	Experience - more risk taking in teens than adults?	Description - more risk taking in teens than adults?	Conducted in fMRI scanner?
Aite	2012	Soochow Gambling Task (Modified IGT)	Experience	12–13	18–32	Yes		No
Beitz	2014	IGT	Experience	11–16	17–59	Yes		No
Cassotti	2011	IGT	Experience	12–14	18–28	Yes		No
Cauffman	2010	Iowa Gambling Task (Play or Pass version)	Experience	10–17	18–30	Yes ^b		No
Crone	2003	Modified Iowa Gambling Task	Experience	12–13, 15–16	18–25	Yes		No
Crone	2004	Hungry Donkey Task (Modified IGT)	Experience	13–15	18–25	Yes		No
Ernst	2003	Iowa Gambling Task	Experience	12–14	21–44	No		No
Overman	2004	Iowa Gambling Task	Experience	11–18	17–23	Yes		No
Van Duijvenvoorde	2012	Modified IGT, Uninformed and Informed	Experience (Uninformed), D +E (Informed)	11–13, 12–14, 14–17	18–29	Yes ^c	No (D+E)	No
Bjork	2007	Chicken	Experience	12–17	23–33	No		Yes
Gardner	2005	Chicken	Experience	13–16	18–22, 24+	Yes		No
Chein	2011	Stoplight	Experience	14–18	19–22, 24–29	Yes ^c		Yes
Kim-Spoon	2015	Stoplight	Experience	17–20	31–51	Yes		No
Steinberg	2008	Stoplight	Experience	10–17	18–30	Yes ^b		No
Braams	2015	BART	Experience	8–27 (Longitudinal data)		Yes		Yes
Mitchell	2008	2BIT (Modified BART)	Experience	14–17	35–55	Yes		No
Figner	2009	Hot and Cold Columbia Card Tasks	D+E (Hot), Description (Cold)	14–16, 17–19	20+	Yes (D+E)	No	No
Van Duijvenvoorde	2015	Hot Columbia Card Task	D+E	16–19	25–34	No (D+E)		Yes
van den Bos	2017	DFD and DFE	Description, Experience	9–22 (Age groups not defined)		Yes	Yes	No
Barkley-Levenson	2013	Mixed Gambles Task	Description	13–17	25–30		No	Yes
Barkley-Levenson	2014	Mixed Gambles Task	Description	13–17	25–30		No	Yes
Burnett	2010	Probabilistic Gambling Task	Description	12–15.5, 15.5–18	25–35		Yes ^b	No

First author	Year	Task	Description or Experience	Adolescent Ages	Adult Ages	Experience - more risk taking in teens than adults?	Description - more risk taking in teens than adults?	Conducted in fMRI scanner?
Engelmann	2012	Probabilistic Gambling Task	Description	12–14, 15–17	18–45		Yes ^c	Yes
Eshel	2007	Wheel of Fortune	Description	9–17	20–40		No ^d	Yes
Habib	2012	Wheel of Fortune	Description	13–15	18–24		No	No
Habib	2015	Wheel of Fortune	Description	13–15	18–23		No	No
Haddad	2014	Wheel of Fortune	Description	11–18	20–38		Yes ^c	No
Keulers	2011	Play-Pass Gambling Task	Description	12–13, 16–17	20–21		No	Yes
Harbaugh	2002	Risky-Safe Gambling Task	Description	14–20 ^a	21–65		No	No
Reyna	2011	Framing Spinner Task	Description	14–17	18–22		Yes ^c	No
Paulsen	2011	Nonsymbolic Economic Decision Making Task	Description	15–16	18–32		Yes ^c	No
Paulsen	2012	Nonsymbolic Economic Decision Making Task	Description	14–15	18–36		No	Yes
Galván	2012	Cups Task	Description	14–17	18–21		No	No
Levin	2014	Cups Task	Description	12–13, 14–15, 16–17	Parents ($M = 45.5$)		Yes	No
Van Leijenhorst	2008	Cake Gambling Task	Description	14–15, 17–18	25–30		No	No
Van Leijenhorst	2010	Cake Gambling Task	Description	12–14, 16–17	19–26		Yes ^{b,c}	Yes
Tymula	2012	Risky/Ambiguous Lottery Game	Description	12–17	30–50		No	No
Blankenstein	2016	Risky/Ambiguous Lottery Game	Description	10–12, 14–16	17–20, 21–25		No	No

Notes.

^aIn this study, the mean age for the adolescent group was unusually high (19.6).

^bOnly one of the adolescent groups (or a subset of the adolescent age range, in Cauffman et al., 2010 and Steinberg et al., 2008) differed from the adult group.

^cThe developmental difference was only found in some conditions (e.g., only some problem types, only in social context, etc.). For more information, please see the main text.

^dIn this study, a portion of the discussion surrounds the lack of a developmental difference, and indeed, the main effect of age on risk taking was not significant. However, in one of the problem types, there was a significant negative correlation between age and risk taking.