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CHAPTER 7

DECISION MAKING IN ADOLESCENCE AND EARLY ADULTHOOD

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Decisions made in adolescence and early adulthood have far-reaching consequences. During this period, individuals set the stage for the rest of their lives in terms of physical and mental health, potential employment, and social connections. Adolescence and early adulthood are marked by elevated levels of risk taking, particularly in domains related to public health (Centers for Disease Control and Prevention [CDC], 2018; for a review, see Reyna & Farley, 2006). The decision of some college-aged individuals to follow through with spring break travel plans during the early days of the COVID-19 pandemic (Bella, 2020) provides a current example of such behavior. Models of risky decision making explain why this might be the case (e.g., Reyna & Farley, 2006; Tymula, 2019). Compared with adults, adolescents may be more impatient or tolerant of ambiguity and sensitive to rewards, or they may be less sensitive to risk, that is, the probability associated with decision outcomes. In addition, differences in traits such as sensation seeking and impulsivity may also play a key role (see, e.g., Casey et al., 2008; Luciana & Collins, 2012; Reyna et al., 2011; Steinberg, 2008). In this chapter, we review these and other factors that influence decision making in adolescents and young adults. Because real-world decision making involves multiple confounded factors, we argue that it is critical to examine distinct features of decision making in the laboratory to understand real-world behavior.

Although the assumption of many researchers has been that risky decisions increase from childhood to adulthood, peaking in adolescence (e.g., Steinberg, 2008), recent research has upended that assumption (Defoe et al., 2015). Overall, research demonstrates a general pattern that children prefer risk more than adolescents, who in turn prefer risk more than adults. As explained later, developmental differences in real-world risk taking likely result from a combination of factors: opportunity to take risks (e.g., having the autonomy and means to make spring break travel plans), tolerance for ambiguity (e.g., being willing to go to the beach when the chances of contracting a virus are unknown), and reward sensitivity and/or impulsivity (e.g., being drawn to the rewarding aspects of partying and spending time with friends and/or an unwillingness to delay a trip until the danger of contracting the virus subsides). Risk preference, or attitude toward uncertain outcomes when the exact probability is known (e.g., 50% chance of winning $100), also plays a role. Accounts of decision making that emphasize developmental differences in traits, such as impulsivity and reward sensitivity, characterize excessive risk taking as a predictable consequence of normal maturation. However, it is important to note that much risk taking during this phase of life is intentional, as contrasted with impulsive sensation seeking, which carries important implications for interventions to address these issues (for

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a review, see Reyna & Farley, 2006). We begin by discussing *why* adolescents behave the way they do—theory—followed by major factors in decision making: ambiguity, time, risk, and reward. *What* commonly used tasks measure are discussed, connections are drawn to real-world examples of risk taking, and areas for future research are highlighted.

MAJOR CONCEPTS AND THEORIES OF ADOLESCENT AND YOUNG ADULT DECISION MAKING

In this section, major theories of adolescent and young adult decision making are discussed, along with approaches to studying age and developmental trends.

Dual Systems Model

Two pioneering papers, both published in a special issue of the same journal in 2008, outlined distinct accounts of what has come to be referred to as the *dual systems* approach (Casey et al., 2008; Steinberg, 2008). According to this approach, adolescent risk taking results from an imbalance between a relatively early maturing reward-based neural system (emphasizing dopaminergic brain systems, including the ventral striatum [VS], i.e., the socioemotional system) and the more protracted development of a cognitive control system focused on the prefrontal cortex (PFC). Steinberg and colleagues' model emphasizes the importance of peers with respect to adolescents' increased propensity toward risk taking (Steinberg, 2008, 2010). In addition, they consider impulsive behavior to be a symptom of prolonged development of the cognitive control (or self-regulation) system (Shulman et al., 2016).

Similarly, in their *imbalance* model, Casey and colleagues emphasize the notion that with age, improved functional connectivity between the limbic and prefrontal regions facilitates better cognitive control and less risk taking (Casey et al., 2008), and they stress that these two systems are not orthogonal (Casey et al., 2016). In contrast, a *triadic* model incorporates an avoidance system, which emphasizes a role for the amygdala, in addition to the PFC and VS (Ernst, 2014). Impulsivity (or low cognitive control) and sensation seeking (or reward sensitivity) are thought to be governed by distinct neural systems, although the neural imbalance approach views these underlying processes as more integrated (Casey et al., 2016).

As noted, impulsivity is a major feature of the dual process and imbalance models, but this term has different definitions throughout the literature on decision making. Broadly, *impulsivity* consists of at least two components: (a) acting without thinking, captured by scales such as "motor impulsivity" on the Barratt Impulsiveness Scale (BIS-11; Patton et al., 1995), and (b) impatience, or the tendency to prefer a sooner, smaller reward instead of a larger, later reward (a.k.a. temporal discounting, discussed later; Romer et al., 2017). Attentional impulsivity and nonplanning (Patton et al., 1995), urgency, and lack of premeditation and perseverance (Whiteside & Lynam, 2001) have also been included in frequently used impulsivity scales. Beyond self-report measures, behavioral tasks are also used to measure impulsivity (Buckholtz et al., 2016; Steinberg, 2010). Therefore, readers must be clear on how impulsivity is defined and measured to meaningfully interpret research regarding adolescent and young adult decision making.

Along with impulsivity, *sensation seeking*, or the extent to which a person is inclined toward exciting or new motivating stimuli (Zuckerman, 1994), is a key feature of theories of risky decision making. Sensation seeking peaks during adolescence, sometime between 15 and 18 years of age (e.g., Duell et al., 2016; Khurana et al., 2018; Reyna et al., 2011). In some formulations, sensation seeking is considered to be related to impulsivity (Romer, 2010)—indeed, some items of the seminal Zuckerman Sensation Seeking Scale (Zuckerman et al., 1978) directly relate to impulsivity, such as "I often do things on impulse." Nevertheless, sensation seeking loads separately from other elements of impulsivity in factor analyses (Whiteside & Lynam, 2001). According to dual systems models, sensation seeking is closely related to reward sensitivity (Steinberg, 2010)—sensation seekers may act impulsively (and despite risks) to pursue rewards (Shulman et al., 2016).

Reward sensitivity can be thought of as the extent to which one is drawn to rewarding stimuli (Reyna et al., 2015). Research using functional magnetic resonance imaging (fMRI) has converged on the VS as a critical region involved in reward-related processing (Galván et al., 2006; Silverman et al., 2015). While "reward sensitivity" is often used synonymously with "VS activation," it is important to keep in mind that other brain regions are also involved, and these regions are also at work during other cognitive functions. Although Poldrack's (2011) *reverse inference* argument cautions against making undue behavioral inferences from brain function, activation in the reward system does have theoretical significance. In addition, although laboratory experiments typically involve money as the "reward," other kinds of rewards are thought to activate similar neural circuitry (e.g., Levy & Glimcher, 2012).

Developmental trends in reward-related striatal activation have been a focus of developmental research over the past 2 decades. In line with dual systems and imbalance models, some results demonstrate an adolescence-specific peak in neural response to reward (e.g., Braams et al., 2015; Galván et al., 2006; van Leijenhorst et al., 2010). However, other results indicate that adolescents show a lower neural response than adults to anticipation of rewarded task performance (Bjork & Pardini, 2015) or find no age effects in response to reward outcomes (Insel & Somerville, 2018), suggesting that a more nuanced understanding of developmental differences in reward sensitivity, and its role in decision making, is warranted (discussed later). Table 7.1 summarizes key features of tasks and findings from the studies referenced here, illustrating the heterogeneity of methods, age groups, and comparisons used. This table highlights a major theme in adolescent and young adult decision making: the importance of (a) using unconfounded tasks to study complex developmental phenomena and (b) attending to critical differences in task features when interpreting research findings. Indeed, a recent meta-analysis collapsing over important, distinct task features, including reward frame (i.e., gain or loss), found that compared with adults, adolescents were more likely to have activation in reward-related brain regions such as the striatum (Silverman et al., 2015), but, as these authors noted, while the method used "elucidates commonalities across diverse paradigms . . . this feature could also be perceived as a limitation" (p. 436). The "commonalities" may be illusory because they collapse over confounds (see the section on task structure).

In addition, developmental differences in sensitivity to differences in expected value have been observed in the striatum (Barkley-Levenson & Galván, 2014) and other value-related brain regions (van Duijvenvoorde et al., 2015). However, brain results do not identify mental processes. Other relevant research has shown that the ability to process differences in expected value develops with age (for a review, see Reyna & Brainerd, 1994; Weller et al., 2011). Hence, tasks examining developmental differences in neural response to reward using gambles of unequal expected value are also confounded with this ability. In summary, although research has shown that, under some circumstances, adolescents exhibit heightened neural sensitivity to reward compared with adults, the presence of other factors that are known to differ developmentally makes attributing differences solely to reward sensitivity questionable.

Fuzzy Trace Theory

In contrast to dual systems and imbalance models, fuzzy trace theory (FTT) posits that there are two main routes to risk taking during adolescence: (a) a *reasoned* route where the risks are traded for rewards of potential decisions by degrees (not merely weighed) such that the magnitude of each matters and offsets the other (as traditional decision theories assume for adult decision making) and (b) a *reactive* route where strong emotions or temptation hold sway and adolescents can fail to inhibit their impulses, acting without thinking (Reyna et al., 2011; Reyna & Farley, 2006). While dual systems and imbalance models assume that mature risk avoidance uses the reasoned route, research and reviews of the literature have shown that adolescents who take risks are more likely to take the reasoned route than are adults who avoid risk.[1] FTT accounts for and predicts both reasoned risk taking as well as impulsive risk taking under

[1]Recent research has also demonstrated that some amount of adolescent risk taking is reasoned in the sense that it is deliberative (i.e., "planned ahead of time"; Maslowsky et al., 2019, p. 249).

TABLE 7.1

Summary of Key Tasks Measuring Neural Sensitivity to Reward

Study	Brief description	Age (years)	Reward	Developmental findings
Galvan et al. (2006)	Incentivized learning task. Three pirate images serve as a cue; two treasure boxes appear on either side of the screen. Subjects indicate on which side of the screen boxes appear. Reward depends on performance (reaction time/accuracy).	Children 7–11 Adolescents 13–17 Adults 23–29	Cartoon images of coins (participants do not know actual value but know they can earn up to $25 for task performance)	Adolescents showed greater signal change in reward region than children or adults (during reward "anticipation" phase, i.e., after responding about where treasure box appeared).
Braams et al. (2015)	Coin flip where subjects select head/tails and correspondingly win/lose money. Reward (and loss) magnitude varies between trials (but some analyses collapse over reward magnitude).	8–27	Three combinations: Win 5/Lose 2 Win 3/Lose 3 Win 2/Lose 5	Quadratic effect of age in neural response to reward outcome (i.e., outcome of coin flip, or "feedback onset")
Van Leijenhorst et al. (2010)	Three slot machines display pictures of fruit. When all three pictures match up (e.g., "XXX") subjects wins 5 cents. "XXY" = first two pictures match but the third picture is different; "XYZ" = all three pictures are different.	Children 10–12 Adolescents 14–15 Adults 18–23	XXX = 5 euro cents	Quadratic pattern: Adolescents exhibited higher neural response to reward in "outcome processing" contrast (XXX–XXY). (No effect of age on "reward anticipation" [XXY–XYZ])
Bjork et al. (2010)	Modified monetary incentive delay task. Subjects see one of five visual cues where they could win or lose $0.50, $5, or nothing by pressing a button when prompted.	Adolescents 12–17 Adults 22–42	Win/Lose $0.50 or $5 per trial	Neural response to reward was greater for adults than adolescents in anticipation of responding to rewarded trials–nonrewarded trials. No age difference in neural activation to reward for notification of reward compared with no reward.
Insel & Somerville (2018)	High-stakes/low-stakes card guessing game. Subjects guess if card is above or below 5 (cards go from 1–9 but not 5).	13–20	High stakes: +$1.00 or –$0.50 Low stakes: +$0.20 or –$0.10	No age patterns in neural reward reactivity (activity in gains compared with activity in losses) was observed.

theoretically specified conditions. Further, FTT predicts a developmental trend away from trading off risk and reward (i.e., compensatory reasoning about probability and outcome magnitude) toward greater emphasis on categorical *gist* thinking that is noncompensatory, as illustrated in, for example, "it only takes once" (e.g., one act of unprotected sex) to get HIV (Mills et al., 2008). This hypothesized (and empirically confirmed) trend toward gist-based thinking in adulthood is the opposite of other developmental theories (e.g., cognitive developmental or dual process theories that contrast socioemotional factors vs. cognitive control, or intuitive vs. analytical or deliberative processes; see Reyna & Brainerd, 2011). Gist-based thinking explains decreased risk taking from childhood to adulthood and cannot be reduced to traditional dual processes (e.g., Evans & Stanovich, 2013; Shulman et al., 2016). Thus, FTT posits that developmental differences in decision making emerge from differences in the reliance on verbatim (precise and literal) processing of risk–reward tradeoffs versus gist (simple but meaningful) representations, along with retrieval of social and moral values relating to risk and reward (Reyna, 2012). More specifically, as age increases from childhood through adolescence into adulthood, individuals gradually transition from relying more on verbatim-based thinking, which emphasizes detailed or literal representations of decision options, to increasingly using gist-based thinking, which emphasizes the bottom line meaning of (and qualitative differences between) decision options (Reyna, 2020). Because verbatim processing emphasizes trading-off by degrees between risk and reward, it promotes risk taking in adolescence when heightened reward sensitivity intensifies perceived rewards (Mills et al., 2008; Reyna et al., 2011).

Age and Developmental Trends

Understanding how age is treated by researchers is critical to understanding developmental trends in decision making. Some note important differences between distinct age groups (e.g., Defoe et al., 2015), while others recommend treating age as a continuous variable (see Hartley & Somerville, 2015). For the former, it is important to understand which ages comprise the designations used, while for the latter, emphasis is on the existence and shape of age-related trends (e.g., linear, quadratic/curvilinear). Further, "adolescence" may sometimes be used to encompass the period referred to as "young or emerging adulthood" (Arnett, 2000). Naturally, researchers who use distinct age groups for purposes of analysis realize that age is a continuous variable, and individual variability is also widely acknowledged, rendering moot many disputes about differences between age categories and continua; age differences are always approximate. Indeed, developmental differences can be understood as individual differences: Some mature adolescents may behave more like adults, whereas some immature adults may behave more like adolescents. These are subtle, but important, ideas to keep in mind in understanding research on this topic.

This chapter emphasizes developmental differences between adolescents and adults and the transition between the two, but developmental differences regarding younger ages are discussed to the extent necessary for understanding developmental trends (e.g., without context, a decline in risk taking from adolescence to adulthood could reflect a monotonic decline from childhood to adulthood or an adolescent-specific nonmonotonic peak, i.e., a quadratic trend).

DISTINCT (YET OFTEN CONFOUNDED) FEATURES OF RISKY DECISION MAKING

As discussed earlier, real-world risky decisions often involve several kinds of uncertainty, such as ambiguity, time delay, and outcome variability (risk). Nevertheless, use of certain laboratory tasks that confuse and confound some or all of these separate components is often encouraged because of ecological validity (e.g., Rosenbaum et al., 2018). Ecological validity is about whether laboratory tasks explain behavior in the real world, not about whether tasks superficially resemble those in the real world. Ecological validity is certainly desirable. However, reliance on ecologically valid yet confounded tasks is problematic for understanding important components of risky decision making and has led to misleading conclusions, which have negative implications for research and practice. The following sections describe recent research regarding these different types of uncertainty, emphasizing developmental trends. Additional confounds common in laboratory tasks (e.g., learning) are also discussed.

Decisions Under Ambiguity

Ambiguity attitude refers to preferences when there are unknowns involved in a decision, such as unknown probabilities or outcomes (e.g., Tymula et al., 2012). The Wheel of Fortune task described in Table 7.2 is an example of a task used to assess ambiguity. Adults are typically ambiguity averse, meaning they do not like ambiguity, and in a pioneering study, Tymula et al. (2012) found that adolescents are more tolerant of ambiguity than adults. Similar findings have been reported more recently, although the reliability and generalizability of this pattern is somewhat in question (cf. Blankenstein et al., 2016, with Blankenstein & van Duijvenvoorde, 2019; Braams et al., 2019; and van den Bos & Hertwig, 2017). Neuroimaging studies indicate that there is some overlap in neural activation associated

TABLE 7.2

Examples of Risky Decision Tasks

Task	Description
Spinner task (e.g., Reyna et al., 2011)	Descriptive. Subjects are presented with a choice between two options (represented by two "spinners")—a sure option (that is entirely one color, e.g., red) and a gamble (where either one half, two thirds, or three fourths of the spinner is another color, e.g., blue, and the remainder of the spinner is red). The blue portions represent the chance of winning nothing (or losing something in the loss frame), and the red portions represent the chance of winning something (or losing nothing). Subjects are asked to decide between the two options (spinners) that systematically vary levels of probability with levels of magnitude (low = $5, medium = $20, and high = $150) so expected values of the two options are equal.
Wheel of Fortune task (e.g., Blankenstein et al., 2018)	Descriptive. Subjects choose between a safe option and a gamble that is either risky (probability of winning something vs. nothing is known) or ambiguous (probability is unknown) based on two wheels that visually depict these probabilities. For ambiguous gambles, part or all of the wheel is covered in gray with a question mark such that probability is unknown. Various levels of probability and ambiguity are used; expected values of the two choice options are not equal.
Lottery task (Braams et al., 2019)	Descriptive. Subjects are presented with a choice between two lotteries. In both they can win money. Within trials, probability is held constant but the decision outcomes are varied such that in one lottery, the outcomes are closer together (less outcome variability) than the other. On some trials, part of the bars representing the lotteries is covered up, introducing ambiguity, but like probability, this level of ambiguity is held constant within trials.
Iowa Gambling Task (Bechara et al., 1994)	Experience-based. Subjects are presented with four decks of cards, two of them "good" (i.e., lower potential rewards and losses and higher expected value) and two of them "bad" (i.e., higher potential rewards and losses and lower expected value). They are instructed to select cards, one at a time, from any deck, and they learn through their selections which decks are "good" versus "bad." Often risk taking on this task is measured by selections from "good" decks minus selections from "bad" decks, but other methods have been used (see Defoe et al., 2015).
Balloon Analogue Risk Task (Lejuez et al., 2002)	Experience-based. Subjects are presented with a balloon that can be inflated by clicking the computer mouse (one click = one pump) and are instructed to inflate the balloon. For each pump, they receive some money (e.g., $0.05). They can stop pumping the balloon at any time and collect the money they have earned, but if they inflate the balloon too much, it pops and they lose all their money for that trial. In some versions of the task, different colored balloons have different probabilities of popping.
Stoplight task (e.g., Chein et al., 2011)	Experience-based. Simulated driving game where the goal is to get to the end of the course as quickly as possible. Monetary rewards are earned for completing the course quickly. Over the course of the game, subjects face numerous intersections with yellow lights, which indicate the possibility of a crash if the light turns red before they get through. Subjects decide whether to stop for the yellow light, which causes a delay, or run the yellow light and either have a longer delay (due to a crash) or no delay (if they make it through the intersection safely). Risk in this task is usually understood to mean not stopping for the yellow light.
Columbia Card Task (Figner et al., 2009)	Descriptive (cold version), but the hot version involves experience (feedback). Subjects are presented with 32 facedown cards (gain or loss) per trial, and play by turning over cards. Trials end when a loss card is turned over (loss amount is subtracted from previous earnings) or when subjects decide to end (if no loss card has been turned over). Subjects know the number of loss cards and amounts of gain and loss; these parameters vary between trials. In the hot version, subjects choose which cards to turn over and get feedback, but in the cold version, subjects decide how many total cards to turn over at the start of each trial.

with the subjective value of decisions involving risk and ambiguity (e.g., in the dorsomedial PFC; Blankenstein & van Duijvenvoorde, 2019) but also evidence of distinct areas of activation for these two types of decisions in both adolescents and adults (see Blankenstein et al., 2018), adding converging evidence that risk and ambiguity attitudes represent distinct aspects of decision making.

To examine attitudes toward ambiguity when both outcomes and probabilities are unknown, van den Bos and Hertwig (2017) created a gambling task that allowed participants to practice making decisions while receiving feedback without consequences before making a final decision that mattered. That is, participants could explore various choices and their associated outcomes in advance. Extent of exploration prior to making a final decision was used to measure tolerance for ambiguity (less exploration = more tolerance of ambiguity). The results showed that adolescents were more tolerant of ambiguity than both children and adults but that the extent of exploration did not correlate with a more traditional ambiguity attitude measure (known outcome, unknown probability). Overall, evidence thus far suggests adolescents may be less averse to ambiguity than adults, although further research using unconfounded tasks will be useful for clarifying this trend.

Decisions Involving Time

A second type of uncertainty involves time: Future outcomes are uncertain. People prefer sooner rewards (all else being equal) but differ in how impatient they are. Impatience is the tendency to forgo later, larger rewards in favor of sooner, smaller ones (e.g., Weigard et al., 2014). For adolescents, decisions favoring sooner, smaller options (i.e., delay discounting, present bias, or failure to delay gratification) have been linked to a host of negative consequences, including substance abuse, academic problems, and poor overall health outcomes (e.g., Bickel & Marsch, 2001; Zayas et al., 2014). *Temporal discounting*, or delay discounting, refers to estimates of the rate of discounting of future outcomes, often measured through a series of questions presenting precise trade-offs between time and money. *Present bias* refers to the special case in which the sooner, smaller reward is available immediately, which is especially enticing.

In general, adults tend to discount less than adolescents; they are more likely to choose the larger, later option over the smaller, sooner option. Discounting declines from childhood to adulthood (de Water et al., 2014; Olson et al., 2007; Romer et al., 2017). However, a recent finding from a large, longitudinal sample of adolescents and young adults (8–25 years old) suggested a quadratic trend with lowest discounting around late adolescence or early adulthood (Achterberg et al., 2016). Note that these authors used "delay discounting" (how much waiting is preferred) and "delay of gratification" (giving in to immediate temptation despite preferring to wait) interchangeably, but these concepts are distinct (see Reyna & Wilhelms, 2017).

Neuroimaging studies have revealed that lower discounting among adolescents and young adults is associated with stronger structural connectivity between the dorsolateral PFC and striatum (e.g., Achterberg et al., 2016) but also negative functional connectivity of these same regions, suggesting that increased structural connectivity might facilitate increased negative functional connectivity (van den Bos et al., 2015). This result is consistent with the hypothesis that top-down inhibition is supported by structural connectivity. In addition, structural MRI has recently revealed that steeper temporal discounting is associated with lower cortical thickness in networks involving the orbitofrontal cortex, ventromedial PFC, temporal pole, and temporoparietal junction in adolescents and young adults (9–24 years old), regions thought to correspond to valuation, cognitive control, and prospection, suggesting potential neural substrates of impulsive choice (Pehlivanova et al., 2018). Together these results suggest that functional and structural neurodevelopmental features help account for developmental trends in delay discounting.

While the literature on delay discounting emphasizes precise tradeoffs between amounts of reward to be received and differences in time intervals, Reyna and Wilhelms (2017) characterized delay of gratification in terms of qualitative thinking (e.g., sacrifice now for a reward later) without regard to exactly how much the reward will be or exactly how much later it will be received. These authors developed a 12-item measure to test gist-based principles of delay of gratification and compared its predictive validity with a large number of alternative measures of delay discounting, sensation seeking, and behavioral inhibition. According to FTT, endorsement of such delay-of-gratification gist principles, which reflect social and cultural values about time, should be protective against risk taking beyond effects of these alternative measures (Reyna & Wilhelms, 2017). The key difference between the FTT approach and traditional temporal discounting is that the former is based on simple qualitative principles represented in long-term memory as gist, rather than degrees of trading off of waiting time versus rewards. Supportive evidence showed that endorsement of delay of gratification gist principles accounted for unique variance (beyond delay discounting and other variables, e.g., numeracy) in predicting financial problems, substance abuse, and overall well-being. In sum, the difference between delay of gratification and temporal discounting, and how decisions involving time are distinct from decisions involving ambiguity as well as risk preference, discussed next, are important distinctions to keep in mind for understanding adolescent and young adult risky decision making.

Risk Preference

Risk preference refers to preferences in situations where both probabilities and outcomes of decision options are known but potential outcomes vary; greater variance indicates more risk (e.g., van den Bos & Hertwig, 2017). For example, a gamble offering a 50% chance of winning $100 is riskier than the option to win $50 for sure (see also Spinner task, Table 7.2). Most people are risk averse for positive outcomes (i.e., gains or rewards; see Reyna et al., 2018), meaning they prefer the less variable outcome; concepts such as diminishing returns (i.e., differences between outcomes matter less as amounts get bigger) in economics are used to account for this observation, as is "discounting" of probabilities in psychology.

A cursory review of the literature on adolescent risky decision making seems to present a confusing pattern, but once distinct features of decision making present in the real world, including distinctions between time delay, ambiguity, and risk preference, are appropriately accounted for through use of unconfounded laboratory tasks, a clearer picture emerges. (The following section describes additional confounds in laboratory tasks that readers should keep in mind.) A recent meta-analysis of the entire literature on adolescent risky decision making showed that risk preference declines from childhood to adolescence (meaning adolescents are more risk averse), declines a little during adolescence, and declines between adolescence and adulthood (Defoe et al., 2015). Subsequent studies have corroborated the overall trend of decrease in risk preference from childhood to adulthood (e.g., Braams et al., 2019), but small differences between adolescents and young adults have been observed. For example, using a Wheel of Fortune task (see Table 7.2), Blankenstein and colleagues reported a small linear increase in risk seeking across adolescence and early adulthood (Blankenstein et al., 2018, sample of 11- to 24-year-olds; Blankenstein & van Dujivenvoorde, 2019, sample of 12- to 22-year-olds).

Neuroimaging studies demonstrate that risk preference is associated with adolescent-specific levels of activation in the insula and dorsomedial PFC—areas associated with risk processing (van Duijvenvoorde et al., 2015). However, other studies have not identified age differences in neural activation in brain areas related to decisions involving risk, such as the ventrolateral PFC, bilateral precentral gyrus, and parietal cortex (Blankenstein et al., 2018), or subjective valuation of decisions involving risk, such as the VS, superior parietal cortex, and dorsomedial PFC (Blankenstein & van Duijvenvoorde, 2019). Note, however, that null effects do not support or refute definitive conclusions about the hypothesis of developmental differences. Additional research using unconfounded tasks will likely help illuminate developmental trends in neurobiological substrates of risk preference.

Crucial for understanding developmental differences in risky decision making, the meta-analytic findings of Defoe et al. (2015) demonstrated a linear decline in risk preference from childhood to adulthood that is fundamentally at odds with the central prediction of dual systems and imbalance models, which predict an adolescent-emergent peak (curvilinear/quadratic trend) in risk taking. According to dual systems and imbalance models, adolescents would be expected to prefer risk more than children and adults. The consistent finding is that they do not; adolescents consistently prefer risk less than children do and about the same as or more than adults do. This overall pattern in risk preference was predicted by FTT (Reyna & Ellis, 1994), which also incorporates a nonlinear developmental trend in reward sensitivity (sensation seeking;

e.g., Reyna et al., 2011). Randomized experiments with adolescents testing FTT's causal mechanisms have also been reported (Reyna & Mills, 2014). Differing developmental patterns for risk preference (monotonic decline) and sensation seeking (adolescent-specific peak) further support the distinction between these constructs.

These findings of decreasing risk preference seem to be at odds with increases in real-life risk taking that peak during late adolescence or early adulthood (e.g., CDC, 2018). However, there are well-documented differences in risk opportunity that have been measured and that account for risk-taking differences across these ages. That is, adolescents have less supervision from adults than children do, and supervision is a known correlate of adolescent risk taking (Gerrard et al., 2008; Reyna & Farley, 2006).

Task Structure

The separate types of uncertainty that comprise real-life risk taking (risk, ambiguity, and time delay) as well as reward sensitivity are often confused and, in some cases, confounded, in laboratory research when outcomes are both variable (risky) and have to be learned based on feedback (ambiguous, at least until learned). Descriptive, as contrasted with experiential, tasks present participants with complete information about magnitudes of potential outcomes and probabilities of obtaining those outcomes (e.g., Spinner task, Table 7.2), and thus do not confound risk preference with ambiguity. In contrast, in experience-based tasks, subjects learn about probabilities and magnitudes by engaging in the task and receiving feedback (see Rosenbaum et al., 2018, and Table 7.2 for examples), and thus these tasks measure both developmental differences in learning as well as decision making. In other words, different learning rates (a.k.a. memory) render decisions in experiential tasks more ambiguous to younger subjects because they learn more slowly from experience; memory differs substantially between childhood and adolescence but more subtly between adolescence and adulthood. Notably, when information is made unambiguous, many developmental differences disappear (van Duijvenvoorde et al., 2012).

In addition to introducing learning as an additional variable, experience-based tasks also confound risk preference with ambiguity attitude (see Rosenbaum et al., 2018) because information about reward outcomes and/or probabilities is unknown at the start of the task. However, the concepts of risk preference and ambiguity attitude are distinct, and it is important to distinguish between the two. Reward can also be confounded with risk when the more rewarding option in a task is riskier (see Balloon Analogue Risk Task [BART], Table 7.2). Further, strategies about outcomes vary developmentally (e.g., gambler's fallacy or win-stay, lose-shift; see Brainerd, 1981). Finally, as Tymula (2019) explained, some descriptive tasks such as the Stoplight task (Table 7.2) involve time: Quick performance is rewarded, and the task involves a series of decisions offering a choice between a certain, shorter delay or the chance of a longer delay or no delay at all. Thus, although Rosenbaum et al. (2018) emphasized that adolescents make more risky decisions than adults in some dynamic, experience-based laboratory tasks while developmental differences are less often observed in descriptive tasks, because experiential tasks often conflate risk with other types of uncertainty or reward, this difference may be accounted for by known differences in learning rates (i.e., memory) across these ages rather than decision-making differences, or it may be difficult to attribute this difference to risk preference per se (instead of some combination of risk preference, ambiguity, time delay, and/or reward).

In addition, in tasks where there is no option for a sure win (i.e., to win anything, a participant needs to choose between two risky options, e.g., Braams et al., 2019, described in Table 7.2), FTT predicts that this forces participants to engage in more precise processing because simple categorical gist distinctions, such as some money versus no money, do not distinguish options (Broniatowski & Reyna, 2018; Reyna, 2012). Because a simpler gist cannot be used, the task forces decision makers to process tradeoffs presented between risk and reward, which elicits higher levels of risk preference, especially in concert with age differences in reward sensitivity. Thus, as predicted by FTT, adolescents take fewer risks than children if a sure option is provided (getting some reward for sure) when that is contrasted with a null outcome in the risky option (possibly getting nothing). But making nothing a possible outcome in both options changes thinking (i.e., no difference between children and adolescents is detected; Defoe et al., 2015).

In sum, when age differences in decision making are of interest, it is uninformative to use tasks that confound risk preference with learning (and therefore ambiguity), the ability to compute expected value, or time delay, or that do not distinguish between offering sure versus risky or both risky options. All of these task characteristics are known to elicit developmental differences. Fortunately, there are clearer tasks (e.g., Columbia Card Task; Figner et al., 2009) that do correlate with real-life risk taking (see Reyna et al., 2011). Some neuroimaging studies have also shown associations between patterns of activation and real-life risk taking (e.g., Blankenstein et al., 2018; cf. Sherman et al., 2018). The link between laboratory tasks and real-life risk taking is an area of active research, but there are several good options to reduce confounds.

Peer Effects

Because adolescents and young adults are particularly attuned to input from peers (for an in-depth discussion on the role of peers in development, see Chapter 14, this volume), peer influence is an important factor to consider with respect to adolescent decision making (see van Hoorn et al., 2016, for a review). Early research regarding peer influence on adolescent and young adult decision making found increases in adolescents' risky decision making under peer observation (Chein et al., 2011; Gardner & Steinberg, 2005; O'Brien et al., 2011; Smith et al., 2015; Weigard et al., 2014). These studies have been interpreted as supporting the hypothesis that peers tap reward sensitivity in adolescence, which then leads to either riskier or more impatient decision making, per the dual systems model (Steinberg, 2008). Such an explanation also suggests that peers increase approach-related responsiveness to reward. However, as explained earlier, some of these studies are based on experiential tasks (e.g., Stoplight task, Table 7.2) that confound multiple important variables, rendering results difficult to parse in terms of separate components of risky decision making (e.g., risk, ambiguity, time, reward). Further, adolescents tend to respond more inconsistently on tasks than adults, which could account for some developmental differences (Tymula, 2019). More specifically, if adolescents appear to be risk averse when alone but less so when peers are present, this change could be due to a true change in risk taking or a more random pattern of response in the presence of peers (assuming a random responder would make risky choices 50% of the time) and thus represents an additional confound to be aware of. Naturally, the original hypothesis of peer effects on socioemotional reward system activation remains a strong scientific explanation; however, recent evidence suggests important nuances to the effect of peers on risk preference (Somerville et al., 2019).

Several studies of the effect of peer influence on adolescents' attitudes toward ambiguity have reported null effects (Blankenstein et al., 2016; Braams et al., 2019; Tymula, 2019). However, in a sample of young adults, Tymula and Whitehair (2018) found that ambiguity aversion increased during peer observation. Although there are far fewer studies of ambiguity compared with risk preference, understanding the underlying causes for their divergent results using unconfounded tasks would be informative.

Recent work examines how adolescents' observation of a peer's risky choices, as opposed to presence of peers during a choice task, might influence risk taking. While adolescents are influenced by peers' risky choices, this is less the case for those in mid- to late adolescence. Blankenstein et al. (2016) found that younger adolescents were more likely to take more risks on a Wheel of Fortune task after observing choices of a (simulated) risk-seeking peer, and Braams et al. (2019) found that older adolescents were the most likely to follow a (simulated) peer's safe choices and least likely to follow risky choices. Through formal model comparison, Ciranka and van den Bos (2019) reanalyzed data from these two studies and demonstrated that information about safety through peer observation was more influential than information about risk for all adolescents.

REWARD PLAYS A PIVOTAL ROLE IN DECISION MAKING

Distinguished from risk, time, and ambiguity preference, reward sensitivity is an important component of major theories of adolescent and young adult decision making. Dual systems and imbalance models emphasize reward sensitivity pulling adolescents toward risky decisions, which immature cognitive control systems cannot control. FTT emphasizes synergies between reward sensitivity and cognitive processing, especially immature trading off of risk for reward. Reward sensitivity or sensation seeking significantly relates to both prosocial behaviors and rebellious risk taking (Blankenstein et al., 2019; Duell & Steinberg, 2020). Thus, reward sensitivity has also been associated with some positive outcomes in adolescence.

Research has also emphasized the developmental integration of reward and cognitive control networks and the importance of this neural connectivity in motivated behavior (see Insel et al., 2017). Prior research suggests that adolescents exhibit adultlike levels of cognitive control when performance is rewarded (Constantinidis & Luna, 2019), although similar results were not observed with a cognitive control task that incorporated positive social cues in the presence of peers (Breiner et al., 2018). The magnitude of the incentive for self-control at stake also seems to play a role (see Insel et al., 2017).

Beyond neural sensitivity to rewards, discussed earlier, some studies have also included a self-report measure of reward rating, or "hedonic experience," using various scales that tap distinct constructs such as arousal, pleasantness, wanting, or cross-domain anhedonia. There is some suggestion of heightened adolescent valuation of reward compared with adults (e.g., de Water et al., 2014), but other studies either fail to detect developmental differences or demonstrate lower ratings of rewards among adolescents compared with adults (Insel & Somerville, 2018; Sullivan-Toole et al., 2019; Wang et al., 2017), despite sometimes identifying age differences in measures such as reaction time or effort (e.g., Rodman et al., 2021). Important distinctions between liking (pleasantness) versus wanting of rewards are well-documented but underemphasized in existing developmental research (Berridge & Robinson, 2016). Thus, future research should develop a better understanding of such distinctions from a developmental perspective.

It is also important to distinguish between overall sensitivity to rewards and reward *magnitude tracking*, or how individuals respond to high versus low magnitude rewards (see Insel & Somerville, 2018). In a group of adolescents (13–20 years old), magnitude tracking of gains was found to decrease linearly with age, while magnitude tracking of losses displayed a concave pattern (Insel & Somerville, 2018). Developmental differences in reward magnitudes have also been examined behaviorally. For example, Reyna et al. (2011) predicted and found that while both adolescents and adults engage in standard framing (choosing gambles in the loss frame more than gambles in the gain frame) when smaller rewards ($5–$20) are at stake, adolescents show a pattern of reverse framing (choosing gambles in the gain frame more than gambles in the loss frame) when large rewards ($150) are at stake. This predicted pattern of reverse framing reflects greater reliance on verbatim-based reasoning (emphasizing differences in magnitude of reward options) and thus ironically reflects reasoned risk taking; reverse framing, too, predicted real-life risk taking, consistent with FTT.

In the context of decisions involving time, reward sensitivity is typically interpreted as wanting rewards sooner—and especially immediately—and has been associated with steeper temporal discounting (e.g., van den Bos et al., 2015). The importance of immediacy has been highlighted in the beta-delta model (which emphasizes bias toward the present; see Duckworth et al., 2018) as well as pioneering neuroimaging studies in adults, where the presence of a distinct reward system for immediate rewards has been debated (Kable & Glimcher, 2010; McClure et al., 2004). Additional research is necessary to better understand how developmental differences in sensitivity or responsiveness to rewards might vary and interact with magnitude and immediacy, as well as their precise influence on delay discounting.

CONCLUSIONS AND FUTURE DIRECTIONS

We have reviewed research regarding adolescent decision making in the domains of risk, ambiguity, and time, along with related key traits such as reward sensitivity, sensation seeking, and impulsivity. In this connection, dual systems and imbalance models (Casey et al., 2008; Steinberg, 2008) have played a pivotal role in research. However, these theories have difficulty accounting for a major result of meta-analyses of the developmental pattern in risk preference: that risk preference decreases from childhood to adulthood, a linear (i.e., monotonic) rather than peaked pattern. The other main theory, FTT, predicts and explains these discrepancies in patterns of risk preference, while including developmental and individual differences in reward sensitivity and inhibition (Reyna et al., 2015). The conceptualization of reward in dual systems and imbalance models as overwhelming an underdeveloped cognitive control system remains viable, but further differentiation of types of reward sensitivity and how they develop in adolescence is warranted. In addition, differences between normative and nonnormative adolescents with respect to risky decision making have been observed (e.g., van Hoorn et al., 2020). Advancing understanding of individual differences and their underlying mechanisms is an important area for future research.

As discussed earlier, a main area for future directions involves a better understanding of the multifaceted role of reward in adolescent and young adult decision making. This involves further exploring developmental differences in separable components of reward (e.g., wanting vs. liking), as well as how reward magnitude influences reward valuation. Because reward is related to risk preference, ambiguity attitude, and decisions involving delay, developing a more fine-tuned concept of reward may help shed light on developmental trends in decision making.

Another key theme in adolescent and young adult decision making that requires future attention is the importance of examining decision making using unconfounded tasks in the laboratory to better understand what accounts for trends observed in the real world. Indeed, several commonly used tasks, such as the Stoplight task, Iowa Gambling Task, and BART (see Table 7.2), cannot be broken down into the separate components of decision making described earlier, limiting the interpretation of their findings (see Tymula, 2019; van Duijvenvoorde et al., 2017). Excellent progress has been made in this regard, and researchers should continue to integrate research in the laboratory with fieldwork to better understand this critical topic.

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