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► **To cite this version:**

Anaïs Osmont, Mathieu Cassotti. Development of ambiguity aversion from early adolescence to adulthood: New insights from the Ellsberg paradox. *International Journal of Behavioral Development*, 2023, 47 (1), pp.47-58. 10.1177/01650254221104056 . halshs-03970209

HAL Id: halshs-03970209

<https://shs.hal.science/halshs-03970209>

Submitted on 6 Jun 2024

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Development of Ambiguity Aversion from Early Adolescence to Adulthood: New Insights from the Ellsberg Paradox

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This article may not exactly replicate the final version published in the journal. The final version is in press in *European Journal of Developmental Psychology*. The exact reference is:

Osmont, A., & Cassotti, M. (2022). Development of Ambiguity Aversion from Early Adolescence to Adulthood: New Insights from the Ellsberg Paradox. *International Journal of Behavioral Development*. <https://doi.org/10.1177/01650254221104056>

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Abstract

This research aimed to clarify whether middle adolescents' risk-taking is driven by reduced ambiguity aversion. In Study 1, we explored the development of ambiguity aversion using an adaptation of the classic Ellsberg paradox with early adolescents (10-11 years old), middle adolescents (14-16 years old) and young adults (20-25 years old). Study 2 examined the development of ambiguity aversion depending on the ambiguity level in middle adolescence compared to adults. These two studies revealed that only early adolescents did not demonstrate ambiguity aversion. In contrast, middle adolescents and adults showed strong ambiguity aversion irrespective of ambiguity level. These findings support the idea that the period of young adolescence could be the start of ambiguity aversion development, although this tendency to avoid ambiguous options is already developed in middle adolescence. This finding might have important public health implications and suggests that prevention campaigns should consider early adolescence to be a particularly vulnerable age group for risky behaviors.

Key words: Adolescence, Decision-making, Ambiguity aversion, Risk-taking, Ellsberg paradox

Introduction

While the probabilities associated with potential outcomes could make our decision-making easier, such information is missing in many real-world decisions. Usually, theorists have distinguished between two types of decision-making based on the uncertainty level (Blankenstein, Huettel, & Li, 2021; Ho, Keller, & Keltika, 2002; Loewenstein, Rick, & Cohen, 2008; Osmont et al., 2015; Rubaltelli, Rumiati, & Slovic, 2010; Smith, Dickhaut, McCabe, &

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Pardo, 2002; Tymula et al., 2012). First, decision-making under risk features situations where decision-makers can assign a probability of occurrence to each of the uncertain outcomes (e.g., a 50% chance of winning \$100 and a 50% chance of losing \$100). Second, decision-making under ambiguity is defined by uncertain outcomes with unknown probabilities (i.e., an unknown probability of winning or losing \$100). Previous studies have converged in showing that people faced with uncertainty have not only a risk aversion - a systematic tendency to prefer a certain option over a risky option (e.g., preference for a sure gain of \$50 over a 50% chance of winning \$100) (Cassotti et al., 2012; De Martino, Kumaran, Seymour, & Dolan, 2006; De Neys, 2012; Kahneman & Frederick, 2007) - but also an ambiguity aversion.

This phenomenon of ambiguity aversion is one of the most robust decision biases; people exhibit a systematic tendency to avoid options with unknown outcome probabilities (Camerer & Weber, 1992; Ellsberg, 1961; Keren & Gerritsen, 1999; Pulford & Colman, 2007a, 2007b, Trautmann & van de Kuilen, 2015). For example, imagine that doctors propose two treatments to combat a disease; the first treatment offers a 50% chance of healing, while the second is associated with an unknown probability of healing. What treatment would you choose? In such situations, most people would prefer the first treatment over the second treatment even if the second option could offer a better chance of survival.

Ambiguity aversion has been extensively studied in adults by economists and psychologists (Camerer & Weber, 1992; Ellsberg, 1961; Fox & Tversky, 1995; Hsu et al., 2005; Inukai & Takahashi, 2009; Keren & Gerritsen, 1999; Levy et al., 2010; Osmont et al., 2015; Pulford & Colman, 2007a, 2007b; Trautmann, Vieider, & Wakker, 2008). The Ellsberg paradox (Ellsberg, 1961) is the emblematic demonstration of ambiguity aversion, which illustrates that people do not decide on ambiguous decisions by assigning subjective probability to each possible outcome, as initially suggested by subjective expected utility theory (SEU; Savage,

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1954). In the demonstration, participants must choose between two urns to draw a winning-color ball (e.g., red balls): a risk urn (Urn A) containing 50 red and 50 black balls and an ambiguous urn (Urn B) containing an unknown ratio of 100 red and black balls. After this choice, the other color (e.g., black balls) becomes the winning balls, and the urn content remains exactly unchanged. According to subjective expected utility (SUE) theory (Savage, 1954), if participants prefer the risky urn over the ambiguous urn with regard to drawing a red ball, then they should assign to the red balls a winning probability lower than 50% in the ambiguous urn (i.e., fewer than 50 red balls and more than 50 black balls in Urn B). Consequently, as the urn contents remain unchanged, the ambiguous urn should be chosen when black becomes the winning color. This reversal of the winning color (e.g., red winning balls then black winning balls) provides a strong measure of ambiguity aversion by testing the persistence of participants' choices. A response pattern involving distinct choices for the two winning colors appears to be the logical response following SEU theory (Savage, 1954). Nonetheless, Ellsberg's results showed that people are largely ambiguity averse and prefer the risky urn over the ambiguous urn irrespective of the winning color.

To explain such decision biases, dual system theories have generally opposed an intuitive-heuristic system (named System 1) to a deliberate-analytic system (named System 2) (Cassotti et al., 2012; De Neys, 2006, 2012; Evans, 2010; Kahneman, 2003; Kahneman & Frederick, 2007). While System 1 operations are typically effortless, rapid and often emotionally charged, System 2 processes are assumed to be slow, effortful, and involve cognitively costly strategies. According to this theoretical framework, ambiguity aversion identified in adults results from an affective and intuitive heuristic belonging to System 1, leading decision-makers to view problems with a lack of information about the level of risk of the options as dangerous (Hsu, et al., 2005; Huettel, et al., 2006; Osmont et al., 2015; see also Levy et al., 2010).

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While numerous studies have corroborated this strong ambiguity aversion in adults (Ho, Keller, & Keltyka, 2002; Inukai & Takahashi, 2009; Osmont et al., 2015; Pulford, 2009, Pulford & Colman, 2007a, 2007b; Smith, Dickhaut, McCabe, & Pardo, 2002; Trautmann et al., 2008), even when the ambiguous urn is mathematically more advantageous (Keren & Gervitsen, 1999), the developmental trajectory of ambiguity aversion from childhood to adulthood is still unclear, especially during middle adolescence (for review Blankenstein et al., 2021).

Some previous studies have supported the hypothesis of a linear development of ambiguity aversion from childhood to adulthood (Blankenstein et al., 2016; Li, Brannon & Huettel, 2015; Li, Roberts, Huettel & Brannon, 2017; Tymula et al., 2012). Indeed, prior studies have indicated that children do not show ambiguity aversion. Using an adaptation from the Ellsberg paradox, Li et al. (2017) showed ambiguity tolerance in 5-year-old children; likewise, 8-year-old children did not prefer a risky gamble over an ambiguous gamble and were willing to bet as much on ambiguous gambles as they were on risky gambles (Li et al., 2015). In addition, Tymula et al. (2012) revealed lower levels of ambiguous aversion in 12- to 17-year-old adolescents than in adult adolescents. Providing larger developmental comparison and using a similar design, Blankenstein et al. (2016) confirmed that ambiguity aversion increased linearly from 10 to 25 but did not show a specific reduced ambiguity aversion during adolescence.

Nonetheless, one recent study also provided discrepant results (van den Bos & Hertwig, 2017). Using a similar design to that used in Tymula et al. (2012) and in Blankenstein et al. (2016), the authors revealed that ambiguity tolerance follows a nonlinear developmental trend from ages 8 to 22, with a peak at 15 to 16 years old. These results are in sharp contrast with the above studies regarding two specific issues. First, while Blankenstein et al. (2016) and Tymula et al. (2012) showed a lower ambiguity aversion in adolescence for gain, van der Bos & Hertwig

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found that ambiguity tolerance peaks in middle adolescence only for loss (e.g., 100% chance of losing \$4 versus a lottery offering a 50% chance of losing \$8 and otherwise nothing). When a gamble involved gain outcomes (e.g., 100% chance of winning \$4 versus a lottery offering 50% chances of winning \$8 and otherwise nothing), the findings did not show significant age differences. Second, nonlinear developmental trends from age 8 to 22 are inconsistent with the results that children do not yet show ambiguity aversion, as suggested by Li et al. (2015, 2017).

Finally, very recent studies did not find clear changes in ambiguity aversion from childhood to adulthood (Blakenstein & van Duijvenvoorde, 2019; Braams, Davidow & Somerville, 2019; Fairley & Sanfey, 2020; Sutter, Kocher, Rützler & Trautmann, 2013). For example, using an adaptation of Ellsberg's urns, Fairley and Sanfey (2020) did not show an effect of age on ambiguity aversion from early to late adolescence and challenged the hypothesis of reduced ambiguity aversion in adolescents compared to adults (see also Sutter, Kocher, Rützler & Trautmann, 2013).

Taken together, prior research has underlined the necessity to further consider the development of ambiguity-attitude from childhood to adulthood (for review Blakenstein et al., 2021).

Significant methodological differences relative to how much probability information is available could partly explain the discrepant results. First, Tymula et al. (2012), Li et al. (2015) and van den Bos et Hertwig (2017) used partial ambiguity situations (e.g., a probability comprised between 40% and 60% of winning \$100), whereas Fairley and Sanfey (2020) or Sutter et al. (2013) exposed participants to complete ambiguity (e.g., a fully unknown probability of winning \$100). Second, the design used by Li et al. (2015, 2017) featured the initial definition proposed by Ellsberg (1961) (i.e., a choice between risky versus ambiguous options). As such, ambiguity aversion is defined as a preference for the risky option over the

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ambiguous option even when they have similar expected values or when the ambiguous option has a higher expected value. In contrast, other studies compared uncertainty aversion in the domain of risk (i.e., certain versus risky options) and the domain of ambiguity (i.e., certain versus ambiguous options). In these studies, uncertainty aversion in the domain of ambiguity is defined as a preference for a certain option over an ambiguous option, even when the two options have the same expected value or when the ambiguous option has a higher expected value. (Blankenstein et al. 2016; Fairley & Sanfey, 2020; Sutter et al., 2013; Tymula et al., 2012; van der Bos & Hertwig, 2017).

Previous studies based on adaptations of the Ellsberg paradox (i.e., involving choices between risky and ambiguous gambles) have provided information about ambiguity aversion from 5 to 8 years old and during adulthood but not during adolescence and only for complete ambiguity situations. This is regrettable given that aversion to ambiguity seems to be an important factor for explaining an increase in everyday risk-taking behavior during adolescence. Indeed, everyday risk-taking behavior can occur in risky situations (i.e., with explicit information about risk level) but mostly occur in ambiguous situations (i.e., without information about outcome probabilities) with various ambiguity levels. For instance, an adolescent is unlikely to be informed about the exact probability of being involved in an accident if he or she decides to drive a scooter without a helmet. According to Tymula et al. (2012), ambiguity-attitude more so than risk-attitude appeared to be predictive of real-life risk-taking (Blankenstein et al. 2016; van der Bos & Hertwig, 2017).

Using the seminal ambiguity aversion task designed by Ellsberg, the current study aims to provide specifications about the developmental trajectory of ambiguity aversion across adolescence in fully (Study 1) and partially ambiguous situations (Study 2). This is a crucial

issue for hypotheses that claim that reduced ambiguity aversion could explain adolescents' everyday risk-taking behavior.

Study 1

Study 1 aimed to clarify the development of ambiguity aversion from childhood to adulthood using an adaptation of the classic Ellsberg paradox in early adolescents (10-11 years old), middle adolescents (14-16 years old) and young adults (20-25 years old).

We reasoned that if ambiguity aversion development follows a linear trend from early adolescence to adulthood (Blankenstein et al. 2016), then ambiguity aversion should be minimal in early adolescence (i.e., no preference for the risky urn over the ambiguous urn) and should be reduced in middle adolescents compared to adults. However, if everyday risk-taking behavior result from a higher tolerance to ambiguity in middle adolescence (Tymula et al., 2012; van der Bos & Hertwig, 2017), then ambiguity aversion might be reduced in the two adolescent groups, especially in 14- to 16-year-olds.

Method

Participants

Study 1 included 90 participants from three age groups: 30 5th-grade early adolescents (10-11 years old, $M = 10.26$, $SD = .45$, 14 males), 30 9th-grade middle adolescents (14-16 years old, $M = 14.3$, $SD = .59$; 15 males) and 30 young adults (20-25 years old, $M = 20.93$, $SD = 1.98$, 16 males). Chi-squared analyses indicated that the gender distribution was not significantly different between the age groups ($\chi^2(1) = .27$, $p = .88$). Informed consent was

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obtained from all adults. Adolescents provided parental written consent and were recruited from their school. The participants were tested in accordance with international norms governing the use of human research participants. According to French law at the time of data collection (Law Jardé), this study did not require licensing committee approval from the Consultative Committees for the Protection of Persons (CPP) because cognitive non-interventional research that is deemed to be of no risk falls outside of the Jardé law. According to university regulations at the time the current study was conducted, investigators made their own determination about exemption from human subjects ethics review. The adult participants did not have any background in logical reasoning or decision-making theory.

Material

All the participants performed an adaptation of the classic Ellsberg urn paradigm (Ellsberg, 1961). This child adaptation consisted of two major modifications. First, real urns were placed in front of the participants, who gave written answers. Red and green balls were placed in two opaque cylindrical urns (diameter = 4.33 inches; height = 7.08 inches). The two urns were identical to avoid a participants' preference due to the urns' design. Second, given that previous works have shown strong ambiguity aversion irrespective of urn size (Pulford & Colman, 2007b), we reduced the total number of balls from 100 to 10.

Procedures

The participants were shown the two urns and received information about the urns' contents: the risky urn contained a total of 10 balls, 5 red balls and 5 green balls, while the ambiguous urn contained a total of 10 balls with an unknown ratio of red and green balls (see Figure 1). The two urns were presented as urn (A) and urn (B), and the urn contents were also

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marked as a reminder on the answer sheet. The urns' presentation order was counterbalanced: urn (A) was the ambiguous urn and urn (B) was the risky urn for half of the participants, while the reverse order was presented to the other half of the sample.

The participants were first taught to imagine that if they drew a red ball (i.e., the winning color), they would win \$10. They were free to choose from either urn (A) or urn (B) to draw a ball: *“Imagine you win \$10 by drawing a red ball. From what urn do you prefer to draw a ball, urn (A) or urn (B)?”* The participants circled their response on the answer sheet. As a manipulation check, they were also instructed to indicate whether they were confident about their answer by completing a 7-point Likert scale ranging from 1 (i.e., not at all confident) to 7 (i.e., completely confident) (i.e., *How confident are you in your choice?*). Indeed, given the uncertainty level of ambiguous options, confidence should be higher for risky choices than for ambiguous choices. In addition, the participants also had to justify their choices to check their understanding of the instructions.

In a second phase, the participants were taught that the content of the two urns remained unchanged, but that green was now the winning color: *“As you see, the urns' contents remain unchanged. I have neither added nor removed any balls. Now, imagine you win \$10 by drawing a green ball. From what urn do you prefer to draw a ball, urn (A) or urn (B)?”* For the first question, the participants circled their response on the answer sheet, indicated whether they were confident on the Likert scale and gave a justification for their choice. Finally, they were asked to indicate their subjective representation of the ambiguous urn's content. The order of the winning colors was also counterbalanced.

[Insert Figure 1]

Data analyses

First, as in previous works (Li et al., 2017), we assessed ambiguity aversion by measuring the number of participants who chose the ambiguous urn versus the risky urn in each group for the first choice (i.e., the first winning color). Chi-square (with Cramer's V) and Fisher's exact tests were used to test whether the distribution of ambiguous versus risky choices differed between the age groups.

Furthermore, the persistence of the participants' choices with the reversal of the winning color (e.g., red winning balls then green winning balls) provided a strong measure of ambiguity aversion. Indeed, we distinguished between four response patterns: (1) ambiguity-aversion pattern (risky-risky: persistent preference for the risky urn); (2) ambiguity-propensity pattern (ambiguous-ambiguous: with a persistent preference for the ambiguous urn); (3) shift pattern (distinct choices for the two winning-colors: ambiguous-risky or risky-ambiguous) with a correct justification as regards SEU theory (justification that respects the principle of subjective probability attribution: e.g., a participant chose the risky urn when the winning color was green because he or she was certain that there were more red balls in the ambiguous urn and then chose the ambiguous urn when red was the winning color for the same reason); and (4) shift pattern following SEU theory (distinct choices for the two winning-colors: ambiguous-risky or risky-ambiguous) without a correct justification as regards SEU theory (e.g., A participant who chose the risky urn when winning color was green because he or she knew the proportion of red and green balls, and then chose the ambiguous urn when red was the winning color because he or she was curious). Chi-square (with Cramer's V) and Fisher's exact tests were used to test whether the distribution of the four patterns differed between the age groups.

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Finally, we performed ANOVAs on the confidence score to test whether the choice confidence level differed between risky and ambiguous choices in early adolescents, adolescents, and adults.

Results

Analysis of risky versus ambiguous first choices

Chi-square analyses and Fisher's exact tests revealed that the distribution of the risky urn versus the ambiguous urn for the first choice differed between the three age groups, $\chi^2(2) = 11.1, p = .004, V = .35$ (Fisher's exact test: $p = .006$) (see Figure 2A). Early adolescents' choices differed from both middle adolescents' choices, $\chi^2(1) = 7.5, p = .006, V = .35$ (Fisher's exact test: $p = .01$), and young adults' choices, $\chi^2(1) = 7.5, p = .006$ (Fisher's exact test: $p = .01$), while there was no difference between adolescents and adults, $\chi^2(1) = 0, p = 1$ *ns* (Fisher's exact test: $p = 1$). Middle adolescents and young adults preferred the risky urn over the ambiguous urns, $\chi^2(1) = 7.5, p = .006, V = .35$ (Fisher's exact test: $p = .01$); however, there was no significant difference in the early adolescent group, $\chi^2(1) = 0, p = 1$ *ns* (Fisher's exact test: $p = 1$).

[Insert Figure 2]

Analysis of response patterns

Chi-square analyses and Fisher's exact tests revealed that the distribution of response patterns differed among the three age groups, $\chi^2(6) = 19.5, p = .003, V = .33$ (Fisher's exact test: $p = .003$) (see Figure 2B). While there was no difference between middle adolescents and

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young adults, $p = .54$ *ns*, the distribution of early adolescents' responses differed from middle adolescents, $\chi^2(3) = 8.79$, $p = .03$, $V = .38$ (Fisher's exact test: $p = .05$), and adults, $\chi^2(3) = 15.3$, $p = .002$, $V = .51$ (Fisher's exact test: $p < .001$) (see Figure 2B).

Chi-square analyses and Fisher's exact tests revealed that the distribution of the four response patterns differed from an uniform distribution among adults, $\chi^2(3) = 22.1$, $p < .001$, $V = .60$ (Fisher's exact test: $p < .001$) and middle adolescents, $\chi^2(3) = 15.81$, $p = .001$, $V = .50$ (Fisher's exact test: $p < .001$), but not among young adolescents, $\chi^2(3) = 3.19$, $p = .36$ *ns* (Fisher's exact test: $p = .39$ *ns*) (see Figure 2B). In fact, ambiguity-aversion is more frequent than other patterns among middle adolescents, $\chi^2(1) = 12.59$, $p < .001$, $V = .45$ (Fisher's exact test: $p < .001$) and adults, $\chi^2(1) = 18.76$, $p < .001$, $V = .55$ (Fisher's exact test: $p < .001$), but not among young adolescents, $\chi^2(1) = .99$, $p = .32$ *ns* (Fisher's exact test: $p = .24$ *ns*).

To further explore these differences, we compared the number of responses in accordance with each profile between the three age groups. No developmental differences appeared for the ambiguity-propensity profile, $p = 1$, and shift pattern responses with justification, $p = .10$ *ns*, but there were age group differences for ambiguity-aversion pattern, $\chi^2(2) = 13.4$, $p = .001$, $V = .38$ (Fisher's exact test: $p < .001$), and shift pattern without justification, $\chi^2(2) = 10.08$, $p = .006$, $V = .33$ (Fisher's exact test: $p = .008$). While early adolescents showed less ambiguity-aversion patterns than middle adolescents, $\chi^2(1) = 6.7$, $p = .01$, $V = .33$ (Fisher's exact test: $p = .01$), and adults, $\chi^2(1) = 11.59$, $p < .001$, $V = .44$ (Fisher's exact test: $p < .001$), there was no difference between middle adolescents and young adults, $p = .28$ *ns*. Finally, the total number of shift pattern responses was higher in early adolescents than in middle adolescents, $\chi^2(1) = 6.65$, $p = .01$, $V = .33$ (Fisher's exact test: $p = .01$), and adults, $\chi^2(1) = 13.42$, $p < .001$, $V = .47$ (Fisher's exact test: $p < .001$).

Analysis of confidence score

We performed two ANOVAs on the confidence scores of the two choices (first choice and second choice), with urn preference (risky versus ambiguous) and age (early adolescents, middle adolescents and young adults) as two between-factors. For both the first choice and the second choice, the ANOVAs revealed an effect of urn preference, choice 1: $F(1,84) = 6.10$, $p = .01$, $\eta^2 = .07$; choice 2: $F(1,84) = 6.70$, $p = .01$, $\eta^2 = .07$, with a lower confidence for ambiguous choices ($M \pm SD$: choice 1: $4 \pm .32$, choice 2: $3.99 \pm .30$) than for risky choices ($M \pm SD$: choice 1: $4.91 \pm .18$, choice 2: $4.91 \pm .18$). There was neither a main effect of age nor an interaction between age and urn preference, all $F < 1$.

Discussion

Study 1 aimed to clarify the development of ambiguity aversion from early adolescence to adulthood using an adaptation of the classic Ellsberg paradox. Two major results emerged from Study 1: 1) middle adolescents (14-16 years old) and young adults (20-25 years old) showed strong ambiguity aversion, and 2) only early adolescents (10-11 years old) did not exhibit ambiguity aversion. More specifically, 10- to 11-year-old participants did not prefer the risky urn over the ambiguous urn for the first choice and gave a more logical response following SEU theory (shift pattern) compared to middle adolescents or adults.

First, the results are in line with numerous studies that have underlined systematic ambiguity aversion in adults (Ellsberg, 1961 ; Hsu et al., 2005; Inukai & Takahashi, 2009; Keren & Gerritsen, 1999; Levy et al., 2010; Osmont et al., 2014; Pulford & Colman, 2007a, 2007b). In this adaptation of the Ellsberg paradox, 83% of the young adults preferred the risky

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urn over the ambiguous urn during the first winning color choice. Furthermore, the persistence of risky choices with the reversal of the winning color (ambiguity-aversion pattern: risk-risk) in 80% of the young adult participants confirms that ambiguity aversion can lead to decisions that transgress the logical response following SEU theory (distinct choices for the two winning colors: ambiguity-risk or risk-ambiguity).

More importantly, our result extends previous findings that 5-year-old children and 8-year-old children do not show ambiguity aversion (Li et al., 2015, 2017). Using a similar design (i.e., choice between a risky and an ambiguous gamble), we found that early adolescents (10-11 years old) showed ambiguity tolerance; i.e., they did not significantly prefer a risky gamble (50% of early adolescents) over an ambiguous gamble (50% of early adolescents) for the first winning color. Only 37% of early adolescents had an ambiguity aversion response pattern when faced with the reversal of the winning color. In addition, our design provides further insight into early adolescents' ambiguity attitudes. Indeed, 10- to 11-year-old participants did not show more ambiguity inclination *per se* compared to middle adolescents or adults, with no more than 20% showing an ambiguity propensity pattern. Interestingly, this reduced ambiguity aversion resulted in a more logical response following SEU theory (shift pattern), even if there were few correct justifications. Indeed, shift pattern responses were dominant in early adolescents (43.33%), in contrast to middle adolescents (13%) and adults (3%).

Dual-process theories and *fuzzy trace theory* provide a developmental framework by which to explain this counterintuitive finding. First, dual-process theories have postulated the development of two intuitive/heuristic System 1 and deliberate/analytic System 2 (Cassotti et al., 2012; De Neys, 2006, 2012; Evans, 2010; Kahneman, 2003; Kahneman & Frederick, 2007). For example, De Neys and Vanderputte (2011) found an aged-related decrease in performance

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between 5 and 8 years of age on conflict base-rate problems (i.e., inconsistency of the cued stereotypical response and the correct analytic response) but an age-related performance increase on no-conflict problems (i.e., consistency of the cued stereotypical response and the correct analytic response). Thus, more logical responses in younger participants could result from the lower need to deal with automatic/affective responses rather than a decrease in analytic thinking skills *per se*. From the same perspective, fuzzy trace theory postulates the development of two parallel decision processes: detail-oriented verbatim processes (e.g., precise/quantitative representation of probabilities) and gist-based representations (e.g., vague/qualitative representation of probabilities) (Reyna, 2012; Reyna & Brainerd, 2011; Reyna & Farley, 2006). Increasing decision-making biases would result from increasing gist processing with age from childhood to adulthood, despite increasing reasoning competencies. Thus, ambiguity aversion may arise from an affective heuristic—leading to the consideration of issues with a lack of information as dangerous—that develop with age and experiences of potential negative outcomes in ambiguous situations (Osmont et al., 2015). In our study, the shift response pattern in early adolescents could follow a lesser need to resist this affective heuristic rather than more logical abilities, as suggested by the small number of correct justifications. In addition, the fact that early adolescents exhibit a lower confidence for ambiguous choices than for risky choices in a similar way than middle adolescents and adults suggests that they detected the higher uncertainty level of ambiguous options.

Critically, our findings extend previous works on middle adolescents' ambiguity aversion. This question of specific ambiguity attitudes during adolescence is a critical issue and has important public health implications. Previous studies have found that ambiguity attitude could predict real-life risk-taking and have assumed that adolescents' engagement in risky behaviors can result from a reduced aversion to ambiguous situations rather than an enhanced

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orientation toward risk *per se* (Tymula et al., 2012; Blankenstein et al. 2016; van der Bos & Hertwig, 2017). Contrary to the findings of Tymula et al. (2012) and Blankenstein et al. (2016), our results did not indicate a significant difference in ambiguity aversion between middle adolescents and young adults. Middle adolescents, similar to young adults, showed massive ambiguity aversion; they largely preferred the risky urn over the ambiguous urn for the first winning color (83,33% of middle adolescents) and persisted in choosing the risky urn despite the reversal of winning color (70% of ambiguity aversion patterns). Only 5% of middle adolescents and adults showed ambiguity propensity. Nonetheless, our results are in line with several previous works that did not show age-related effects on ambiguity aversion from early to late adolescence (Blankenstein & van Duijvenvoorde, 2019; Braams, Davidow & Somerville, 2019; Fairley & Sanfey, 2020; Sutter, Kocher, Rützler & Trautmann, 2013). Our results are also consistent with those of van der Bos and Hertwig (2017), who found a peak in ambiguity tolerance during middle adolescents only for loss gambles but no age-related differences for gain gambles.

Taken together, our results suggest that ambiguity aversion progressively develops with age and accumulates experiences of potential negative outcomes in ambiguous situations until early adolescence. These findings contradict the hypothesis of a reverse U-shaped trajectory of ambiguity aversion with maximal tolerance during middle adolescence. However, these results, which are inconsistent with those of Tymula et al. (2012) and Blankenstein et al. (2016), may result partly from an important design disparity. Our study is limited to situations that involve full ambiguity, while the previous studies distinguished between variable ambiguity levels (i.e., partial ambiguity of 25%, 50%, 75% or full ambiguity of 100%). In fact, ambiguity level appears to be a crucial factor in apprehending developmental specificities in ambiguity aversion. Thus, Study 2 aims to address this issue.

Study 2

Study 1 findings contradict the hypothesis of a reverse U-shaped trajectory of ambiguity aversion with maximal tolerance during middle adolescence. Indeed, middle adolescents and adults show similar ambiguity aversion. However, contrary to Tymula et al. (2012) and Blankenstein et al. (2016), Study 1 provides evidence of strong ambiguity aversion in middle adolescents and adults only for full ambiguity situations. As a result, we cannot rule out that middle adolescents could have specific ambiguity attitudes when facing partially ambiguous situations. Study 2 focused on middle adolescence and adulthood with a manipulation of ambiguity level to test this specific hypothesis. More specifically, we aimed to examine the development of ambiguity aversion depending on the ambiguity level in middle adolescence (13-15 years old) compared to young adults (19-25 years old). This is an important issue because real-world risky behavior often occurs in situations where adolescents do not face full ambiguity but rather receive partial information about potential outcomes. For Study 1, we used an adaptation of the classic Ellsberg paradox with a manipulation of 5 distinct ambiguity levels. Based on Tymula et al. (2012), middle adolescents should show reduced ambiguity aversion compared to adults irrespective of ambiguity level. Ambiguity aversion should increase with ambiguity level only in adults. However, if ambiguity aversion develops in early adolescence, as suggested by Study 1, then middle adolescents such as adults should be strongly ambiguity averse irrespective of the proportion of ambiguity.

Method

Participants

Study 2 included 214 participants from two age groups: 101 8th-grade middle adolescents (13-15 years old, $M = 13.36$, $SD = .64$; 35 males) and 113 young adults (19-25 years old, $M = 20.66$, $SD = 1.81$, 28 males). The participants were randomly assigned to one of five experimental conditions. Chi-squared analyses indicated that the gender distribution was not significantly different between the age groups ($\chi^2(1) = 2.05$, $p > .15$) or between conditions in either adolescents ($\chi^2(4) = 1.95$, $p > .50$) or adults ($\chi^2(4) = .89$, $p > .90$) (see Table 1). Informed consent was obtained from all adults included in this study, and adolescents provided parental written consent.

Table 1

Group characteristics in the 5 experimental ambiguity level conditions

	Ambiguity level Condition	N	Female (Male)	Mean Age (SD)
Middle adolescents N = 101	A = 20%	22	16(6)	13.77(.62)
	A = 40%	20	14(6)	13.1 (.31)
	A = 60%	23	14(9)	13.26 (.54)
	A = 80%	16	11(5)	13.25 (.44)
	A = 100%	20	11(9)	13.35(.48)
Young Adults N = 113	A = 20%	23	18(5)	20.39 (1.77)
	A = 40%	23	16(7)	21 (1.91)
	A = 60%	23	18(5)	20.75 (2.16)
	A = 80%	23	18(5)	20.77 (1.66)
	A = 100%	21	15(6)	20.71 (1.65)

Material and procedures

The materials and procedures used were identical to those used in Study 1, except that we defined five ambiguity levels. Depending on the condition, the participants had to choose between a risky urn (i.e., 10 balls, 5 red balls and 5 green balls) and an ambiguous urn as

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follows: complete ambiguity (i.e., 10 unknown-color balls); 80% partial ambiguity (i.e., 8 unknown-color balls, 1 red ball and 1 green ball); 60% partial ambiguity (i.e., 6 unknown-color balls, 2 red balls and 2 green balls); 40% partial ambiguity (i.e., 4 unknown-color balls, 3 red balls and 3 green balls); 20% partial ambiguity (i.e., 2 unknown-color balls, 4 red balls and 4 green balls) (see Figure 3).

[Insert Figure 3]

Data analyses

As in Study 1, we conducted three distinct analyses: Chi-square (with Cramer's V) and Fisher's exact tests were used to test whether the distribution of ambiguous urns versus risky urns for the first choice (i.e., the first winning-color) differed between the age groups and the five ambiguity levels and whether the distribution of response patterns (ambiguity-aversion pattern/ambiguity-propensity pattern/shift pattern with a correct justification as regard SEU theory/shift pattern without a correct justification as regard SEU theory) differed among the age groups and the five ambiguity levels. To test whether choice confidence differed between middle adolescents and adults depending on the ambiguity level, we also performed two ANOVAs on the confidence scores of the two choices (first choice and second choice), with urn choice (risky versus ambiguous), ambiguity level (A20%; A40%; A60%; A80% and A100%), and age (middle adolescents and adults) as the three between-factors.

Results

Analysis of risky versus ambiguous first choices

Chi-square and Fisher's exact tests revealed that the distribution of risky urns versus ambiguous urns for the first choice did not differ between middle adolescents and adults irrespective of the ambiguity level [Fisher's exact test: $A = 20\%$: $p = 1$ ns; $A = 40\%$: $p = 1$ ns; $A = 60\%$: $p = .24$ ns; $A = 80\%$: $p = .50$ ns; $A = 100\%$: $p = .24$ ns] (see Figure 4). Indeed, middle adolescents, similar to adults, preferred the risky urn over the ambiguous urns [*middle adolescent*: $\chi^2(1) = 20.19$, $p < .001$, $V = .32$, Fisher's exact test: $p < .001$; *adult*: $\chi^2(1) = 19.11$, $p < .001$, $V = .29$, Fisher's exact test: $p < .001$], while the risky versus ambiguous choice repartition did not differ between ambiguity level for the two age groups [Fisher's exact test: *middle adolescent*: $p = .63$, *adult*: $p = .44$.]

[Insert Figure 4]

Analysis of response patterns

Fisher's exact tests revealed that the distribution of response patterns differed between the two age groups only for the 100% ambiguity level [$A = 20\%$: $p = .11$ ns; $A = 40\%$: $p = .64$ ns; $A = 60\%$: $p = .43$ ns; $A = 80\%$: $p = .61$ ns; $A = 100\%$: $p = .009$ ns] (see Figure 5). For the 100% ambiguity level, while there was no difference between middle adolescents and adults for the ambiguity aversion pattern and the shift with justification pattern [Fischer's exact test: ambiguity aversion pattern: $p = .53$ ns; shift responses without justification: $p = .74$ ns], the number of shift responses without justification was greater in middle adolescents than in young

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adults, Fisher's exact test: $p = .05$, $V = .32$, and the number of ambiguity propensity was greater in young adults than in middle adolescents, Fisher's exact test: $p = .03$, $V = .35$.

Finally, the number of ambiguity aversion patterns did not differ following ambiguity level, either for middle adolescents, $p = .82$ *ns*, or for young adults, $p = .86$ *ns*.

[Insert Figure 5]

Analysis of confidence score

For the first choice as for the second choice, the ANOVAs revealed no significant effect of the urn choice, *choice 1*: $F(1,194) = 1.80$, $p = .18$, $\eta_p^2 = .01$; *choice 2*: $F(1,194) = 2.83$, $p = .09$, $\eta_p^2 = .01$, no main effect of ambiguity level, *choice 1*: $F < 1$; *choice 2*: $F < 1$, and no interaction between ambiguity level and urn choice, *choice 1*: $F < 1$; *choice 2*: $F < 1$. However, there was a marginally significant effect of age for the first choice, $F(1,194) = 3.05$, $p = .08$, $\eta_p^2 = .016$, and a significant effect of age for the second choice, $F(1,194) = 8.31$, $p < .01$, $\eta_p^2 = .041$, with a lower confidence score for middle adolescents, *choice 1*: $4.37 \pm .16$, *choice 2*: $4.12 \pm .16$ ($M \pm SD$), than for young adults, *choice 1*: $4.75 \pm .15$, *choice 2*: $4.74 \pm .14$. There was no interaction between age and urn choice, *all* $F < 1$, or between age and ambiguity level, *choice 1*: $F(4,194) = 1.17$, $p = .33$, $\eta_p^2 = .02$; *choice 2*: $F(4,194) = 1.59$, $p = .18$, $\eta_p^2 = .02$]; neither was there a 3-level interaction, *all* $F < 1$.

Discussion

Study 2 aimed to test whether middle adolescents showed specific ambiguity aversion compared to young adults depending on ambiguity level. Two major results confirmed and

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extended the findings of Study 1; i.e., 1) middle adolescents, similar to young adults, showed strong ambiguity aversion even for minimal ambiguity levels, and 2) for the two age groups, the size of ambiguity aversion did not depend on ambiguity level.

In a recent study, Fairley and Sanfey (2020) suggested that ambiguity level could explain the previous discrepancy results. Our results did not provide evidence in support of this hypothesis. Indeed, 13- to 15-year-old middle adolescents and young adults showed strong ambiguity aversion, irrespective of ambiguity proportion. We did not find significant age-related effects on the number of risky gamble choices for the first winning color or for ambiguity averse patterns for all ambiguity levels. Previous works have already shown that children and adolescents are not sensitive to ambiguity level (Li et al. 2015; Tymula et al. 2012). However, while Tymula et al. (2012) found reduced ambiguity aversion in adolescents even for maximal ambiguity levels, our results indicated strong ambiguity aversion—similar to that found in adults—even for minimal ambiguity levels. Eighty-two percent of middle adolescents and seventy-nine percent of adults preferred the risky urn over the ambiguous urn at the 20% ambiguity level. Moreover, the proportion of ambiguity averse response patterns did not differ between middle adolescents and adults.

Finally, our results are also inconsistent with previous works revealing that adults are sensitive to ambiguity level (Blankenstein & van Duijvenvoorde 2019; Tymula et al. 2012). Indeed, our adult participants did not show ambiguity-level sensitivity. This discrepancy could result from the between-subjects design we used to manipulate the ambiguity level. According to the comparative ignorance hypothesis (Fox & Tversky, 1995), ambiguity aversion requires a comparison with less ambiguous events and disappears in a noncomparative context. Although our design clearly involves a comparison between an ambiguous option and a less

uncertain option, we cannot rule out that a within-subjects design allowing a direct comparison of various ambiguity levels might be more favorable to ambiguity aversion and the emergence of an ambiguity level effect in adults. Future studies should address this issue.

General discussion

Our findings are in sharp contrast with the hypothesis that middle adolescents show reduced ambiguity aversion compared to adults, as suggested by Tymula et al. (2012). The studies discussed here support the idea that young adolescence could be the start of ambiguity aversion development (Blankenstein et al., 2016) and suggest that this tendency to prefer risky over an ambiguous option is already developing in middle adolescence, irrespective of ambiguity level. This research underlines that ambiguity level is not enough to explain the discrepant results about ambiguity aversion development during adolescence (Fairley & Sanfey, 2020). Middle adolescents, like adults, show strong ambiguity aversion even for minimal ambiguity levels. Interestingly, the lack of effect of the ambiguity levels is keeping with the *fuzzy trace theory* and might suggest that ambiguity aversion involves gist processing in middle adolescents.

However, the inconsistent results could be explained by other substantial methodological disparities. First, the large age range of the adolescent group (i.e., from 12 to 17 years old) could partially explain Tymula et al.'s (2012) findings. Second, our design, similar to that of Li et al. (2015, 2017), provides an evaluation of ambiguity aversion in accordance with the initial definition proposed by Ellsberg (1961) (i.e., a preference for the risky option during choices between a risky and an ambiguous gamble). In other studies (Blankenstein et al. 2016; Tymula

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et al., 2012; van der Bos & Hertwig, 2017), participants had to choose between a sure option and an ambiguous option. As such, this design opposes two options that are associated with distinct reward values (e.g., \$5 for the sure option versus \$20 for the ambiguous gamble). Given the enhanced reward sensitivity in middle adolescence (Braams, van Duijvenvoorde, Peper & Crone, 2015; Galvan, 2010; Somerville, Jones and Casey, 2010; Van Leijenhorst et al., 2010), the preference for the ambiguous gamble could be driven by the larger reward. Moreover, this reward sensitivity could lead adolescents to focus on the potential reward more than the uncertainty level, especially when gamble probabilities are unknown (i.e., only information about rewards is available for ambiguous gambles). In contrast, adaptation of Ellsberg's task, as the one we used in the present study, involved reward values that were strictly similar between the two options, allowing a more direct test of ambiguity aversion.

Finally, ambiguity is also a decisive construct used to understand adolescent risk-taking in social-emotional contexts. For example, two recent studies have shown that middle adolescents showed an impairment of feedback-based learning during ambiguous risk-taking tasks compared to adults (Osmont et al., 2017) and were thus more likely to follow peer influence in such ambiguous situations (Osmont et al., 2021). On the other hand, Blankeinstein et al. (2016) found that social context impacts risk attitudes but not ambiguity attitudes. Further studies are needed to clarify whether distinct social contexts could influence ambiguity attitudes.

Limitations

The current study has several limitations that should be acknowledged. First, our participants did not play for real monetary payoffs. Nonetheless, previous works showed similar results when the experiments involved real payoffs and participants were paid according to their

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choices (Sutter et al., 2013). Similarly, we cannot rule out that the subjective value of \$10 would vary by age and whether it could interact with age-related ambiguity aversion findings. Futures studies should address these questions. Second, we aimed to closely feature the initial definition of ambiguity aversion, but this adaptation of the Ellsberg paradox is a single trial of two choices, which could limit the sensitivity. In the same way, this single choice design did not allow us to explore whether ambiguity aversion—similar to uncertainty aversion in the domain of ambiguity—is negatively related to real-life adolescents' risk-taking. Future studies should address this important point. Moreover, even if the present study supported the suggestion that ambiguity aversion emerges between young adolescence and middle adolescence, future researchers may also include more adolescent groups to understand the exact developmental trajectory of ambiguity aversion more precisely.

Conclusion

These two studies revealed that only early adolescents do not demonstrate ambiguity aversion. Indeed, middle adolescents and adults showed strong ambiguity aversion irrespective of ambiguity levels. These findings support the idea that the period of young adolescence could be the start of ambiguity aversion development. This finding might have important public health implications and suggests that prevention campaigns should consider early adolescence to be a particularly decisive age for risky behaviors.

Supporting Information and data

Additional tables are available as supporting information. For the two studies, these tables provide:

- Risky (R) versus ambiguous (A) choices for the first winning color (first choice) and

the second winning color (second choice)

- Response pattern distributions
- The subjective representation of the ambiguous urn's color

Data are available on the platform OSF:

https://osf.io/s6axu/?view_only=8bbb287d549a4ca2a91fd68b0d244c6c.

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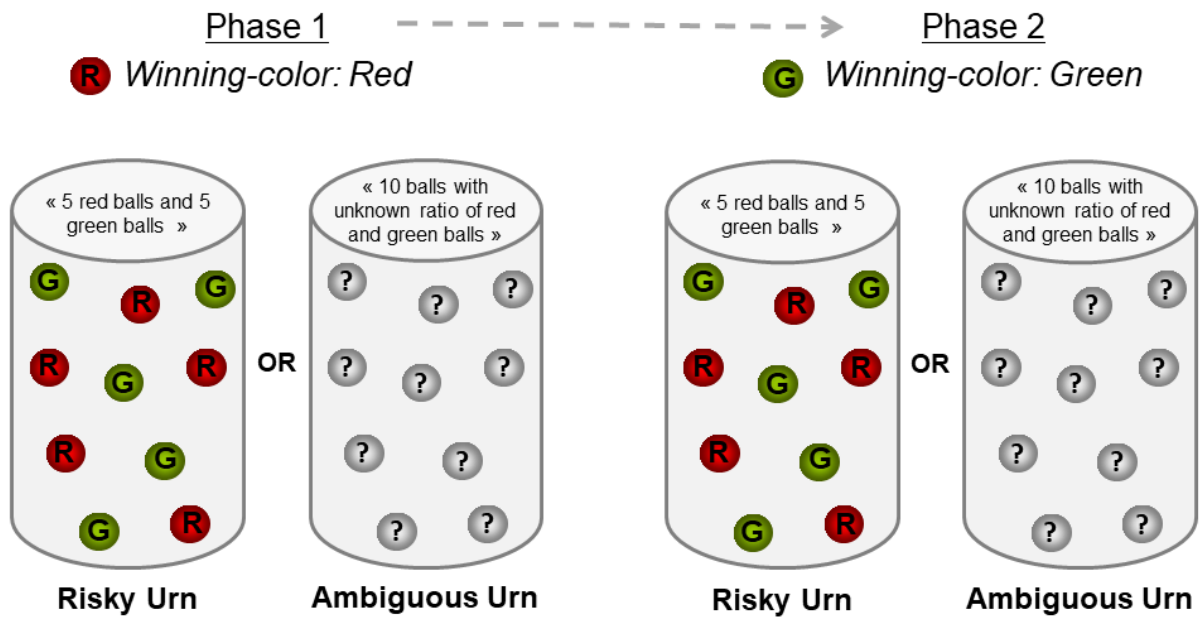


Figure 1: Materials and design. Two opaque urns were displayed to the participants. Participants were informed that the risky urn contained 5 red and 5 green balls, while the ambiguous urns contained 10 balls with an unknown ratio of red and green balls. The content of the two urns remained unchanged, but the winning color changed between the two phases of the task.

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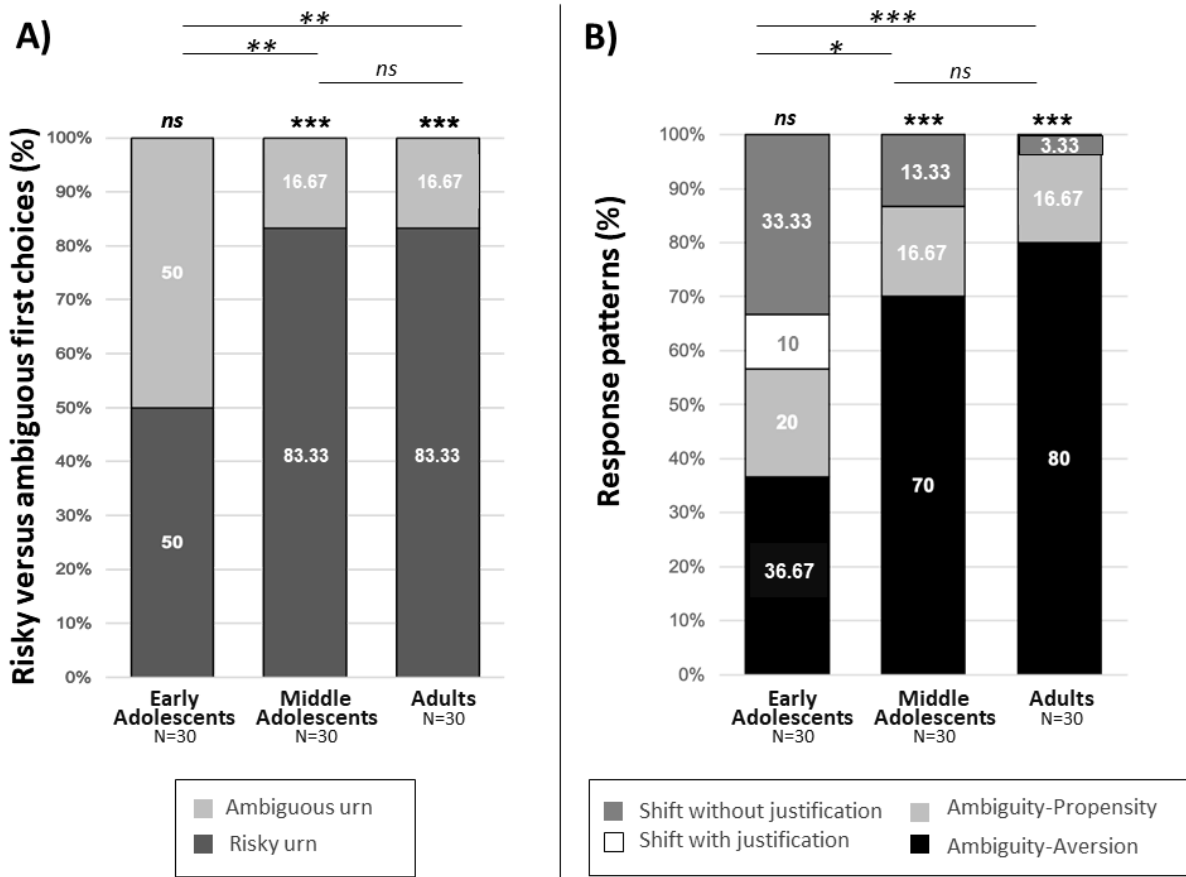


Figure 2: A) Risky versus ambiguous choices (%) for the first winning color in early adolescents, middle adolescents and adults. Adolescents, similar to adults, preferred the risky urn over the ambiguous urn, while there was no difference in early adolescents. B) Response patterns (%) for the three age groups. (ns = $p > .05$; * = $p < .5$; ** = $p < .01$; *** = $p < .001$; italic type refers to age-group differences and bold type refers to within-group differences)

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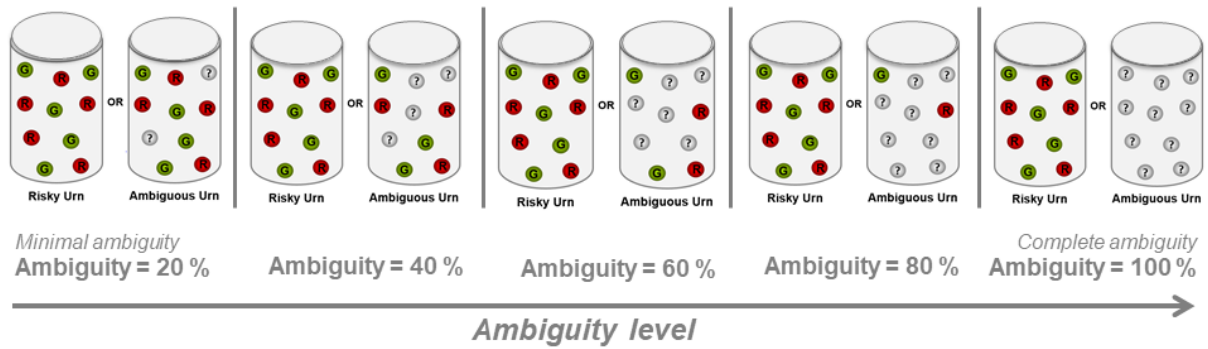


Figure 3: Materials and design. Two opaque urns was displayed to the participants: the risky urn containing 5 red and 5 green balls, and the ambiguous urns containing 10 balls with a variable level of ambiguity (Ambiguity=100%, Ambiguity =80%, Ambiguity =60%, Ambiguity =40%, Ambiguity =20%.)

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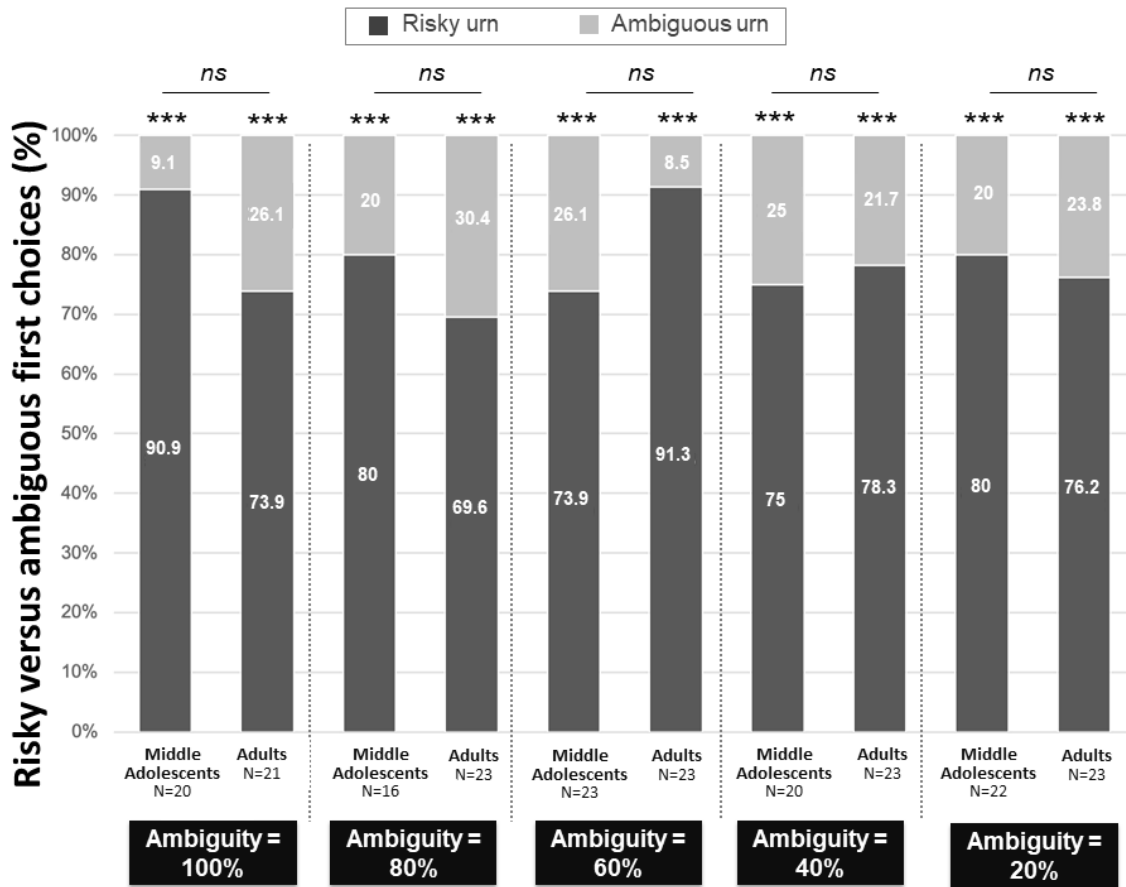


Figure 4: Risky versus ambiguous choices (%) for the first winning color in middle adolescents and adults and for the five ambiguity levels. Adolescents, similar to adults, preferred the risky urn over the ambiguous urn, irrespective of ambiguity levels. (ns = $p > .05$; * = $p < .5$; ** = $p < .01$; *** = $p < .001$; italic type refers to age-group differences and bold type refers to within-group differences)

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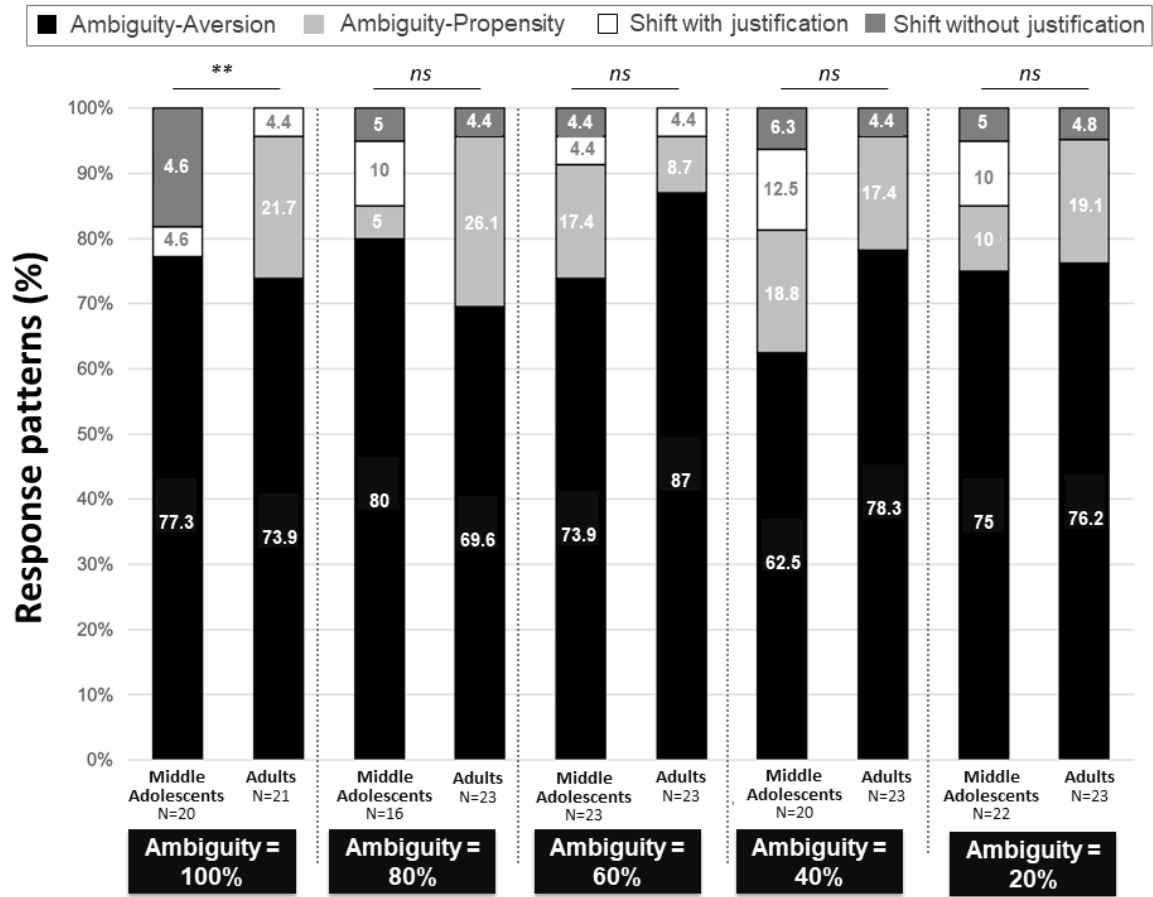


Figure 5: Response patterns (%) in middle adolescents and adults and for the five ambiguity levels. (ns = $p > .05$; * = $p < .5$; ** = $p < .01$; *** = $p < .001$; italic type refers to age-group differences)