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EMPIRICAL ARTICLE

CHILD DEVELOPMENT

Do adolescents use choice to learn about their preferences? Development of value refinement and its associations with depressive symptoms in adolescence

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Abstract

Independent decision making requires forming stable estimates of one's preferences. We assessed whether adolescents learn about their preferences through choice deliberation and whether depressive symptoms disrupt this process. Adolescents aged 11–18 ($N = 214$; participated 2021–22; Female: 53.9%; White/Black/Asian/Mixed/Arab or Latin American: 26/21/19/9/8%) rated multiple activities, chose between pairs of activities and re-rated those activities. As expected, overall, participants uprated chosen and downrated unchosen activities ($dz = .20$). This value refinement through choice was not evident in younger participants but emerged across adolescence. Contrary to our predictions, depressive symptoms were associated with greater value refinement. Despite this, more depressed adolescents reported lower value certainty and choice confidence. The cognitive processes through which choice deliberation shapes preference develop over adolescence, and are disrupted in depression.

Adolescence is a time of increasing independence and decision-making autonomy. While children's daily activities tend to be determined by their caregivers, across adolescence young people increasingly make more of their own decisions—what clothing to wear, what music to listen to, and how, where, and with whom to spend time. Alongside the affordances adolescents are given to expand their decision-making space, they also appear to actively seek out opportunities to explore their options, displaying increased risk-taking (Leather, 2009), forging new friendships (Berndt & Hoyle, 1985) and exploring novel real-world environments (Saragosa-Harris et al., 2022). It has been proposed that this exploratory behavior allows adolescents to learn about themselves and the world (Ciranka & van den Bos, 2021; Lloyd et al., 2021), but the exact cognitive mechanisms that support this are not well understood. Here, we propose that the act of making choices itself may help adolescents to reassess and refine their own preferences, and thus learn about themselves; we investigate how this ability evolves across adolescence and whether it is disrupted in depression.

We suggest that individuals can update and refine their estimates of their own preferences through choices, even when their consequences are not directly experienced. This is demonstrated in the free-choice paradigm, in which participants are initially asked to make subjective "value" ratings (i.e., how much one anticipates liking or enjoying) of multiple items. The term "value" is used here and throughout this paper in line with the neuroeconomics literature, to refer to the subjective desirability of a particular outcome. In the case of the free-choice paradigm, previous experiments have asked participants to rate their subjective value of various "outcomes," for example, snacks, activities, or holidays. Items are then paired in a manner that produces both "easy" (differently rated) and "difficult" (closely rated) choices, and participants are asked to

Abbreviations: BIC, Bayesian information criterion; MFQ-SF, Mood and Feelings Questionnaire—Short Form; RcRP, ratings, color choices, ratings, preference choices; RPR, ratings, preference choices, ratings; SoA, spreading of alternatives.

choose between paired items, for example, whether they would rather have a pretzel or a chocolate bar. Finally, participants are asked to rate all items a second time. A consistent finding is that most participants display "spreading of alternatives" (SoA): items that were chosen are re-rated more favorably, with the opposite pattern for unchosen items. This "choice-induced preference change" has a substantial effect size and has been widely replicated (Enisman et al., 2021). Choice-induced preference change has been reported to persist over several years and has been demonstrated in infants and children and even non-human primates (Egan et al., 2007; Sharot et al., 2012; Silver et al., 2020; although these studies do not account for alternative explanations, which we discuss in detail below).

Here, we argue that SoA occurs because of a process of "value refinement" during choice deliberation (Lee & Daunizeau, 2020; Lee & Pezzulo, 2023). Again, "value" is used here to represent an individual's estimations of the anticipated enjoyment of particular outcomes (i.e., value estimates). The account posits that the observed change in ratings is due to the refinement of value estimates that occur during choice deliberation. Lee and Daunizeau (2020) argued that the process of deliberating over choice alternatives allows participants to become more precise in their evaluations. To elaborate, for every item presented in the free-choice paradigm, participants hold an underlying value estimate represented as a distribution (a representation of how enjoyable the snack or activity would be, with an associated degree of certainty). When asked to rate the items, participants draw from this value distribution to give a value rating. During choice deliberation, the value distributions of the presented items are perturbed toward the direction of choice (the distribution for the item that will eventually be chosen shifts positively, with the converse for the item that eventually will be rejected) and the widths of the items' distributions narrow. In this way, participants have learned about their preferences through choice deliberation, by reassessing and reducing uncertainty over their preferences. When they are asked to re-rate each item, they draw from this new value distribution, creating SoA, where the chosen item's value rating increases and the unchosen item's value rating decreases. The account posits that when choices are difficult (i.e., between items that were similarly rated or that participants were uncertain about), this encourages participants to reassess the options and gain certainty over their value estimates until they can reach a satisfactory level of choice confidence. In support of this proposal, SoA was found to be strongest when similarly rated items were paired together in choice, and when participants reported being least certain about their initial value ratings but were able to eventually reach a confident choice (Lee & Coricelli, 2020; Lee & Daunizeau, 2020, 2021); further evidence for this view was presented in a recent simulation study (Lee et al., 2023).

We propose that this "value refinement" could elucidate a mechanism that may support adolescents to develop a better sense of their own preferences through independent choice. We suggest that this could support self-concept development, a key feature of adolescence (Harter, 2012). In the current study, we investigate the development of adolescents' preferences for leisure activities, which, although perhaps not core to self-concept, may contribute to building a sense of identity, for example, as a "skater," "basketball player," or "bookworm." Further, value refinement through choice might serve as a more general mechanism through which adolescents learn about themselves, enabling a sharpening of preferences for school subjects, career options, self-identification, or political beliefs. Value refinement may also help to explain adolescents' propensity toward increased exploration (Ciranka & van den Bos, 2021). Exploring the environment expands one's decision-making space, and increases opportunities to make choices between novel options; the value refinement account suggests that the very act of making choices, especially between uncertain options, may help adolescents to sharpen estimates of their own preferences and thus learn about themselves.

Early adolescence has been highlighted as an important period for self-concept development, marked by major changes to physical appearance, relationships with caregivers and friends, and self-reflection (Crockett & Petersen, 2021; Moses-Payne et al., 2022; Schaffhuser et al., 2017; Simmons et al., 1979, 1987). We hypothesized that younger adolescents may be less certain about their preferences and thus more motivated to refine them (or their uncertainty enables such refinement). According to the value refinement account, lower certainty in value estimates should lead to greater deliberation during choice and greater value refinement as a result. We, therefore, predicted that there would be an age-related decline in SoA as adolescents gain certainty over their preferences and choices require less deliberation. At the same time, key cognitive competencies that support effective learning from decisions may still be maturing during adolescence. Previous work has demonstrated age-related differences during adolescence in the ability to reflect on decisions (Moses-Payne et al., 2021; Weil et al., 2013) and to sensibly incorporate others' advice or external information into decisions (Schwarz & Roebers, 2006). Therefore, it remains possible that younger adolescents, although perhaps more motivated to learn about themselves, may not yet have the capacity to use value refinement to learn from their choices and we may instead observe an age-related increase in SoA as these capacities develop.

It is important to note that the value refinement account is not the only proposed explanation of SoA. For many years, SoA was interpreted as reflecting cognitive dissonance reduction. This account posits that once a choice is made, any negative feelings about the chosen

item (or positive feelings about the unchosen item) will create an unpleasant state of cognitive dissonance because of the contradiction between participants' choice behavior and their feelings. According to this account, in order to reduce dissonance, participants engage in a post-hoc justification of their choices by increasing/decreasing their value ratings of the chosen/unchosen items, respectively. The cognitive dissonance account differs from value refinement in two key ways: first, changes in value estimates are posited to occur in post-hoc deliberation *after* a decision has been reached, rather than *during* the process of choice; and second, that choice leads only to perturbation in value estimates, but not to reduction in uncertainty. Evidence that SoA is stronger when participants are initially less certain about their ratings but eventually reach a confident choice (Lee & Coricelli, 2020; Lee & Daunizeau, 2020, 2021) is interpreted as contradicting the cognitive dissonance account, which would predict greater dissonance (and therefore stronger SoA) when participants were highly certain about their initial value ratings but made a low-confidence choice. In the current study, we aimed to replicate this evidence in favor of the value refinement account, by asking adolescents to rate their certainty after every value rating and confidence after every choice.

Finally, an important challenge to both the value refinement and cognitive dissonance accounts came from Chen and Risen (2010), who argued that a statistical artifact could produce an apparent SoA, even without any actual shift in the underlying value distributions. When the experimenter pairs choice alternatives that are initially similarly rated, the value rating for the more-liked item is likely to have been drawn from the lower end of its value distribution, and the value rating for the less-liked item from the upper end of its distribution. The subsequent choice between these two items would then typically reflect the direction of the difference in the underlying value distributions, with the more-liked item more likely to be chosen. Then, when participants are asked to rate the two items again there will be a regression to the means of the respective distributions, with the chosen item being re-rated more favorably (moving away from the lower tail of the higher distribution) and the opposite pattern occurring for the unchosen item (moving away from the higher tail of the lower distribution). Importantly, Chen and Risen (2010) demonstrate that apparent SoA can be observed using a design where no choices are made between the two sets of ratings but instead, after both ratings have been made. In this case, it is clearly impossible for the change in ratings to have been "induced" by the choice.

The account that the SoA is driven entirely by this statistical artifact has been challenged by a number of studies using controlled designs to show that, in adults, SoA is stronger when choices occurred between the ratings rather than after, when choices were made between the ratings but were made by a computer (Izuma et al., 2010; Salti et al., 2014), when choices were implicit rather than explicit (Alós-Ferrer et al., 2012) or when participants were blind to the choices as they made them (Enisman et al., 2021; Izuma et al., 2015; Johansson et al., 2014; Luo & Yu, 2017; Miyagi et al., 2017; Nakamura & Kawabata, 2013; Sharot et al., 2010; Taya et al., 2014). Another challenge was recently demonstrated using simulation analysis showing that this explanation cannot account for many patterns of data observed in the free-choice paradigm (Lee & Pezzulo, 2023). In the current study, we included a control choice condition, in which participants made choices according to the color of the stimuli images, to account for the statistical artifact.

Adolescence is also marked by the onset of mental health problems such as depression (Kessler et al., 2007; Solmi et al., 2022). A growing literature suggests that altered decision-making and preference formation in adolescence may indicate risk for depression (Forbes et al., 2007; Forbes & Dahl, 2012). For example, a longitudinal study on 11-year-old boys demonstrated that a lower tendency to choose high-probability high-reward options was associated with depressive symptoms 1 year later (Forbes et al., 2007). This implies that for some young individuals at risk of developing depression, rewards may not elicit typical approach behaviors. Consequently, this could hinder a young person's ability to gauge their preferences accurately, because environmental stimuli fail to trigger their normal appetitive responses. As a result, adolescents at risk of depression may experience difficulties forming their preferences, which, in turn, could disrupt their decision-making abilities. Indeed, depressed adults and adolescents often report indecisiveness (Kent et al., 1997; Leykin & DeRubeis, 2010). One suggested factor contributing to indecisiveness in depression is lower decision confidence: in adults, depressive symptoms have been associated with lower confidence in the absence of feedback (Rouault et al., 2018) and greater post-decision adjustment of confidence in light of new evidence (Moses-Payne et al., 2019). Although preliminary evidence in adults suggests depressive symptoms may be associated with alterations to choice-induced preference change (Miyagi et al., 2017), the mechanisms of value certainty and decision-making confidence have not yet been assessed. We hypothesized that adolescents with more depressive symptoms would not be able to use choice deliberation to gain certainty over their value estimates, and so would show lower SoA (lower value refinement), and would not be able to resolve their uncertainty in a confident choice.

Overall, the present study aimed to test three main hypotheses. First, we sought to demonstrate that SoA is not exclusively driven by statistical artifact but, rather, is at least partly driven by value refinement (Hypothesis 1). Second, we hypothesized that older adolescents would

exhibit lower value refinement through choice than younger adolescents because they would hold greater initial value certainty and would require less deliberation to reach a confident choice (Hypothesis 2). Finally, we hypothesized that adolescents with more depressive symptoms would exhibit lower value refinement through choice than those with fewer depressive symptoms because they would hold less initial value certainty, but be less able to reach a confident choice and remain uncertain about their preferences after choice (Hypothesis 3). In summary, we predicted that both older (compared to younger) adolescents and more depressed (compared to less depressed) adolescents would show lower value refinement through choice, albeit due to different mechanisms.

METHODS

Participants

Participants were recruited from publicly funded secondary schools in London, UK. Data was collected in 2021–2022. For participants under 16 years of age, we gained parental consent and participant assent. Participants over 16 years of age consented to take part themselves. Each participant was given a voucher valued between £7 and 9.50 depending on their performance in another cognitive task (not reported here). The study was approved by the University College London Research Ethics Committee (ID: 14261/001).

We recruited 242 participants and analyzed data from 214 participants. Participants were excluded if the correlation between their first and second ratings was less than 0.5 ($n=8$) if they failed at least three times in at least two instruction quizzes ($n=4$) or for technical issues (incomplete data, $n=14$; images did not load, $n=1$). One participant withdrew consent to take part in the study.

Participants were aged 11–18 (11.29–18.51, $M=14.96$). This age group was chosen to span a wide developmental window but also to ensure testing conditions were similar across participants (all participants took part in groups in classroom settings and were paid with vouchers). Participants were 59.35% ($N=127$) female sex, with one participant not disclosing their sex.

In order to explore the role of socioeconomic status in choice-induced preference change, participants' indices of multiple deprivation were estimated according to their postcode using 2019 UK Government deprivation data (https://imd-by-postcode.opendatacommunities.org/). This measure is based on seven domains of deprivation with the following weights: income deprivation (22.5%), employment deprivation (22.5%), education, skills and training deprivation (13.5%), health deprivation and disability (13.5%), crime (9.3%), barriers to housing and services (9.3%) and living environment deprivation (9.3%). We included participants with indices of multiple deprivation spread across the entire range (1–10; $M=4.73$, SD = 2.33), representing the local populations of the schools recruited for the study.

Parents provided ethnicity for children under 16 and participants over 16 provided ethnicity for themselves. Ethnicity was divided into five categories: (1) Asian, Asian British or Any other Asian background (19%); (2) Black, African, Caribbean or Black British (21%); (3) Mixed or multiple ethnicities (9%); (4) Other ethnic group (Arab or Latin American; 8%) (5) White (26%). Seventeen percent of participants' ethnicity was missing.

CIPC task

Piloting

We completed three pilot studies during the development of the task with 18- to 24-year-olds (total $N=224$) recruited via the online recruitment platform, Prolific. Through this process, we extended previous work to design a paradigm that: (1) used a within-subjects design to contrast two conditions: (i) ratings, preference choices, ratings—RPR and (ii) ratings, color choices, ratings, preference choices—RcRP; (2) controlled for exposure to the stimuli; (3) included instruction quizzes to ensure participants understood the task. We also optimized the number of trials to ensure adolescents could complete the task in a single session and used pilot data to set our exclusion criteria.

Stimuli

Stimuli were 80 images and descriptions of age-appropriate activities, for example, 10-pin bowling, visiting a theme park, or playing football. Activities were generated by 117 11- to 14-year-olds to ensure that they would be appropriate and familiar to adolescent participants. To prompt the generation of activities, we asked "Can you think of activities you would do on a Saturday if there was no pandemic? Think of at least three fun and three boring activities". Matching images were gathered from the copyright-free online database, Unsplash. For each participant, 40 image-description pairs were selected at random. The task was implemented using Javascript, HTML, and CSS and hosted on Gorilla.sc.

Experimental design

Participants completed the task in four parts: (1) initial value ratings; (2) choices (two blocks: preference and color, with the block order counterbalanced); (3) second value ratings and (4) preference choices. Task display and procedure are shown in Figure 1.

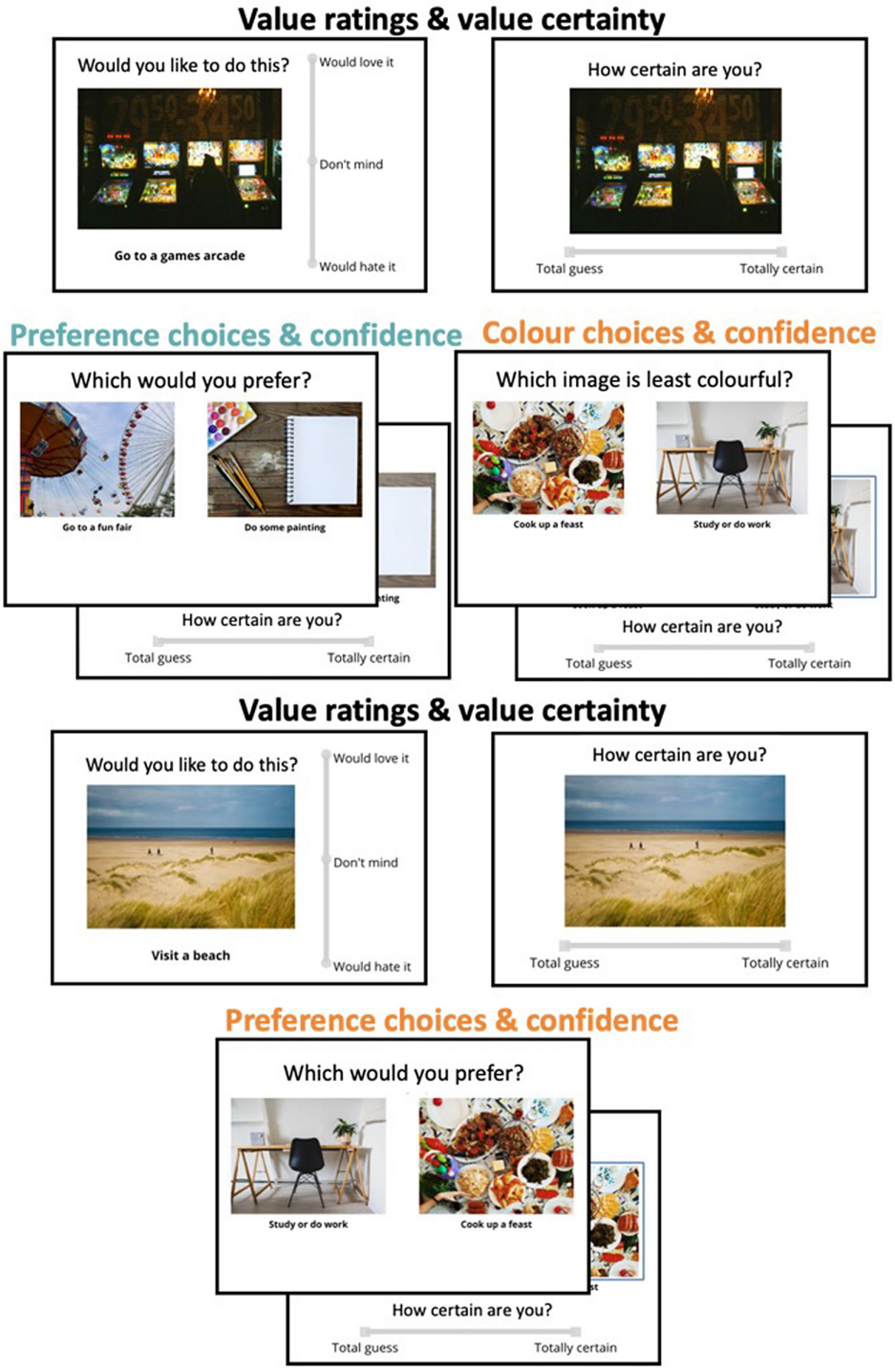

FIGURE 1 Task procedure. Forty activities were randomly selected from a set of 80 activities and presented in a random order. Participants made 40 initial ratings and 10 choices in each condition. Activities presented in the color choices between ratings were presented again in the final preference choices. Choices were completed in blocks. The order of preference choices and color choices was counterbalanced. The order of activities in the second rating was randomized.

Instructions

Participants were instructed that they should imagine it was Saturday, sunny and that there was no pandemic. Before starting the task, participants were instructed on the value and confidence rating scales. Participants were instructed to think carefully about their ratings. After making their ratings, participants were instructed on the choice section of the task and were asked to complete a three-question quiz on the instructions (used as an exclusion criterion). If they failed the quiz, participants returned to the start of the instructions. Participants were also asked to complete an instruction quiz whenever

the choice blocks changed, to ensure they understood whether they needed to answer according to preference or color. The number of times participants needed to re-start the instructions was recorded and used as an exclusion criterion.

Ratings

During the first and third parts of the task, participants were asked to make a value rating and associated certainty rating for all 40 activities. Participants viewed an image and description of the activity in the center of the screen. For the value ratings, participants were prompted with "Would you like to do this?" and rated the activity on a scale from 0 to 100. The scale had labels at 0 "Would hate it", 50 "Don't mind" and 100 "Would love it". For the certainty ratings, participants were prompted with "How certain are you?" and rated their certainty on a scale from 0 to 100. The scale had labels at 0 "Total guess" and 100 "Totally certain". To avoid anchoring, the slider tooltip remained hidden until the participant's first click. The tooltip numerical value was not displayed to participants.

Choice pairing

After the initial ratings, activities were paired to create 20 choice trials. We aimed to create 10 "close" pairs (activities that were similarly rated) and 10 "distant" pairs (activities that were rated differently) of activities. Activities were binned into 20 equally-sized bins (width of 5 points) according to their initial ratings. To create close pairs, a single bin was selected at random and two activities from this bin were paired. To create distant pairs, two bins were selected at random, one item was taken from each bin and paired. Close pairs were created initially, followed by distant pairs. If there were insufficient bins to create all 10 distant pairs, activities were selected from the same bin so that participants were always presented with a minimum of 10 close pairs. The number of pairs of activities that were initially rated within 5 points of one another ranged from 10 to 17 ($M = 12.25$, SD = 1.82). Pairs of activities were displayed in a random order (randomly allocated to either a preference choice or color choice in part two of the task) and the item with the highest initial value rating was randomly allocated to the left or right side of the screen.

Choices

During the second and fourth parts of the task, participants made choices between pairs of activities. In the second part, participants completed 20 choice trials: 10 in which they chose according to which activity they would prefer (which we term "preference" choice) and 10 in which they chose which image was least colorful (which we term "color" choices). In the preference choice block, participants were presented with two images and image descriptions side-by-side on the screen and were prompted with "Which would you prefer?". In the color choice block, the choice display was identical except participants were prompted with "Which image is least colorful?". In both blocks, participants responded by clicking on the activity image. Once the image was clicked, a confidence scale appeared. Participants were prompted with "How certain are you?" and rated their confidence from 0 "Total guess" to 100 "Totally certain". The order of the choice blocks was counterbalanced between participants. During the final part of the task, participants chose which activity they would prefer for the 10 choice pairs that had previously been presented during the color choice block in part two. Otherwise, the procedure was identical to the preference block in the second part of the task.

Conditions

Stimuli were split into two conditions. First, the RPR condition, in which participants rated the activities, made preference choices between the activities, and then re-rated the activities. These activities did not appear in the final part of the task. Second, the RcRP condition, in which participants rated the activities, made color choices between the activities, re-rated the activities, and then made preference choices between the activities. All participants completed the task with all activities in a within-subjects design. All activities were paired using the same algorithm irrespective of condition (see Choice pairing section).

Questionnaire and non-verbal reasoning

Participants completed the Mood and Feelings Questionnaire—Short Form (MFQ-SF; Sharp et al., 2006), which consists of 13 items. The MFQ-SF has been validated in 11- to 18-year-olds (Rhew et al., 2010; Sharp et al., 2006; Turner et al., 2014) for the measurement of depressive symptoms. The total score was used in analyses, and missing values (17 participants with 1 missing value; 3 participants with 2, 3, and 5 missing values respectively; 1 participant with 12 missing values) were imputed using the mean of completed items. Five participants did not complete the MFQ-SF.

Participants completed the nine-item abbreviated version of the Raven Standard Progressive Matrices (Bilker et al., 2012).

Overview of procedure

Participants completed the task and questionnaire reported here, as well as another experimental task and two further questionnaires (not reported here). Participants initially provided consent (over-16 s) or assent (under-16 s). They then completed the two experimental tasks (one not reported here) followed by the

Raven's matrices and finally the questionnaires. The order of the tasks was counterbalanced but the Raven's matrices and questionnaires were always presented after the tasks.

Statistical analysis

Spreading of alternatives

The magnitude of participants' choice-induced preference change was calculated using SoA:

$$\text{SoA} = [\text{rating\#2} - \text{rating\#1}]_{\text{chosen}} - [\text{rating\#2} - \text{rating\#1}]_{\text{unchosen}}.$$

SoA was calculated for all choice pairs. Activities were categorized as chosen or unchosen according to preference choices in part two (for SoA-RPR calculation) or part four (for SoA-RcRP calculation) of the task (ignoring color choices for the latter). For trial-level mixed-effects analyses, we used the trial-level SoA and marked each score as RPR or RcRP. For linear regression analyses, we calculated two separate scores—SoA-RPR and SoA-RcRP—by taking the mean SoA value across all pairs of activities in each condition for each participant, as well as a difference score (SoA-RPR minus SoA-RcRP).

Statistical models

For mixed-effects models, data was analyzed using trial-level data using the *lme4* package in R. All models were linear mixed-effects models, with participants as random intercepts. We report the main effects and interaction effects of the best-fitting models using omnibus Type III χ^2 Wald tests. These are further probed with planned and post hoc comparisons using the *emmeans* package (Lenth et al., 2018). For all models, we included random intercepts only because including maximal random slopes led to a singular model fit. This failure to converge is common in models with greater complexity and indicates that the model is over-specified, thus removing random slopes simplified the models, allowing them to converge (Barr, 2013). For linear regression models, we used base R (*lm* function) and reported beta estimates.

We included the following covariates: sex, ethnicity, index of multiple deprivations, number of participants in the testing room, and Raven's matrices score. When constructing our models, we initially tested each covariate individually against the outcome of interest. We then included only covariates that were significantly associated with the outcome of interest in each model (see Table S1 for model equations).

We used Bayesian Information Criteria to compare various functions of age (see Supporting Information for model comparison details).

Justification of sample size

An a priori power analysis was conducted using G*Power (Faul et al., 2007) to determine the minimum sample size required to test our prediction that there would be an age-related decrease in the SoA-RPR but not in SoA-RcRP. The required sample size to achieve 80% power for detecting a small effect size (f^2) of .05 (equivalent to $r = .25$), at a significance criterion of $\alpha = .05$, was $N = 196$ for a linear multiple regression with two tested predictors (age and age-squared) and six control predictors (number of participants in the room, gender, ethnicity, income, non-verbal reasoning score, SoA-RcRP). We recruited 242 participants to allow for ~20% exclusions and the final sample size for analysis was $N = 214$ participants.

All analyses were hypothesis-driven, except where stated otherwise. We conducted some additional exploratory analyses to further investigate unexpected age-related associations with SoA-RcRP.

RESULTS

Choice-induced preference change and value refinement (Hypothesis 1)

We first aimed to demonstrate that choice-induced preference change is not entirely driven by the statistical artifact, but instead, is at least partly driven by value refinement (H1). According to this hypothesis, we made the following predictions: (i) SoA will be stronger when preference choices are made between (RPR) rather than after (RcRP) ratings; (ii) SoA-RPR, but not SoA-RcRP, will be strongest when participants are least certain about their initial value ratings but rectify their uncertainty in a confident choice; (iii) In the RPR condition only, value certainty will increase from the initial to the second ratings and (iv) the second value ratings will be better predictors of choices than the initial ratings.

SoA is larger when participants make choices between ratings rather than after

As expected, participants demonstrated a significant mean SoA, which was evident both when preference choices occurred between the ratings (RPR: $t(213) = 13.59$, $p < .001$; $dz = .93$; M ± SD = 7.26 ± 7.81; Figure 2, top panel) and when they occurred after the ratings (RcRP: $t(213) = 9.72$, $p < .001$, $dz = .66$; M ± SD = 4.74 ± 7.13; Figure 2, middle panel). In both conditions, participants uprated chosen and downrated unchosen activities to the same extent (see Supporting Information).

Importantly, the SoA was significantly greater when preference choices occurred between the ratings (RPR) compared with when they occurred after both ratings had been completed (RcRP) (SoA-difference:

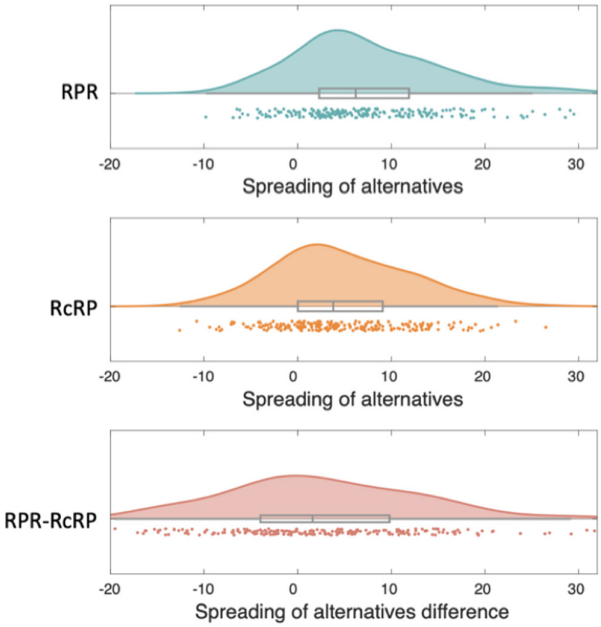

FIGURE 2 Spreading of alternatives (SoA). Raincloud plots distribution of participants' mean SoA for the ratings, preference choices, rating condition (RPR; top panel), the ratings, color choices, ratings, preference choices condition (RcRP; middle panel) and difference (RPR-RcRP, bottom panel). Points show the mean SoA for each individual participant. Boxes in gray represent the interquartile range and median. SoA-difference represents mean SoA-RPR minus SoA-RcRP.

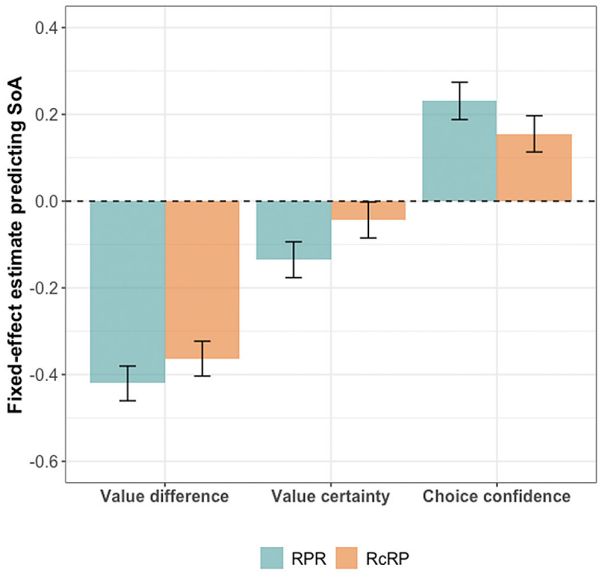

FIGURE 3 Choice features associated with spreading of alternatives (SoA). *Y* axis shows fixed effect estimates in a model predicting trial-level SoA. RPR, ratings, preference choices, and ratings condition; RcRP, ratings, color choices, ratings, and preference choices condition. Error bars show standard error.

$t(213) = 3.68$, $p < .001$, $dz = .20$; $M \pm SD = 2.52 \pm 12.63$; Figure 2, bottom panel; prediction 1i). Therefore, a significant effect of SoA remained after controlling for (within-subjects) the expected effect from the statistical artifact.

SoA is largest when resolving value uncertainty in a confident choice

According to the value refinement account, SoA should be strongest for choice pairs that required greater deliberation (low-value rating difference, low-value certainty) but were resolved in a confident choice (prediction 1ii). We, therefore, assessed the association between SoA and three measures: (1) the difference in initial ratings between two alternatives (chosen minus unchosen); (2) average value certainty across the two alternatives; and (3) choice confidence. First, we used linear mixed-effects models with value difference, value certainty, and choice confidence, as well as their interactions with choice condition (RPR vs. RcRP) as fixed effects (Figure 3). We then tested the interaction between value certainty and choice confidence and its impact on SoA (Figure 4), to specifically test the hypothesis that SoA results from the resolution of value uncertainty during choice deliberation.

There was a significant negative association between value difference and SoA ($\chi^2 = 312.37$, estimate = .36, SE = .02, $t = 17.67$, $p < .001$) such that, as expected, choosing between activities with a smaller difference in initial value ratings was associated with a larger SoA. This association was significantly stronger for SoA-RPR than SoA-RcRP (value-difference-by-choice-condition interaction: $\chi^2 = 3.91$, $p = .048$; $\text{slope}_{\text{RPR}} = -.42$, SE = .02, $p < .001$, $\text{slope}_{\text{RcRP}} = -.36$, SE = .02, $p < .001$, $\text{contrast}_{\text{RPR-RcRP}} = -.06$, SE = .03, $p = .048$).

There was also a significant negative association between value certainty and SoA ($\chi^2 = 4.22$, estimate = −.04, SE = .03, $t = -2.05$, $p = .040$), such that, as expected, choosing between activities with a lower initial mean value certainty was associated with a larger SoA. Again, this association was significantly stronger for SoA-RPR than SoA-RcRP ($\chi^2 = 9.93$, $p = .002$; $\text{slope}_{\text{RPR}} = -.14$, SE = .02, $p < .001$, $\text{slope}_{\text{RcRP}} = -.04$, SE = .02, $p = .040$, $\text{contrast}_{\text{RPR-RcRP}} = .09$, SE = .03, $p = .002$).

Finally, there was a significant positive association between choice confidence and SoA ($\chi^2 = 52.74$, estimate = .16, SE = .02, $t = 7.26$, $p < .001$), such that, as expected, SoA was larger when participants reached a confident choice. This association was significantly stronger for SoA-RPR than for SoA-RcRP ($\chi^2 = 6.32$, $p = .012$; $\text{slope}_{\text{RPR}} = .23$, SE = .02, $p < .001$, $\text{slope}_{\text{RcRP}} = .16$, SE = .02, $p < .001$, $\text{contrast}_{\text{RPR-RcRP}} = .08$, SE = .03, $p = .012$).

When analyzing the interaction between value certainty and choice confidence, as predicted by the value refinement account we found that participants showed a stronger SoA on trials where they were initially less certain about their value ratings but nonetheless still reached a confident choice. This interaction was specific to the RPR condition, with a significant interaction between

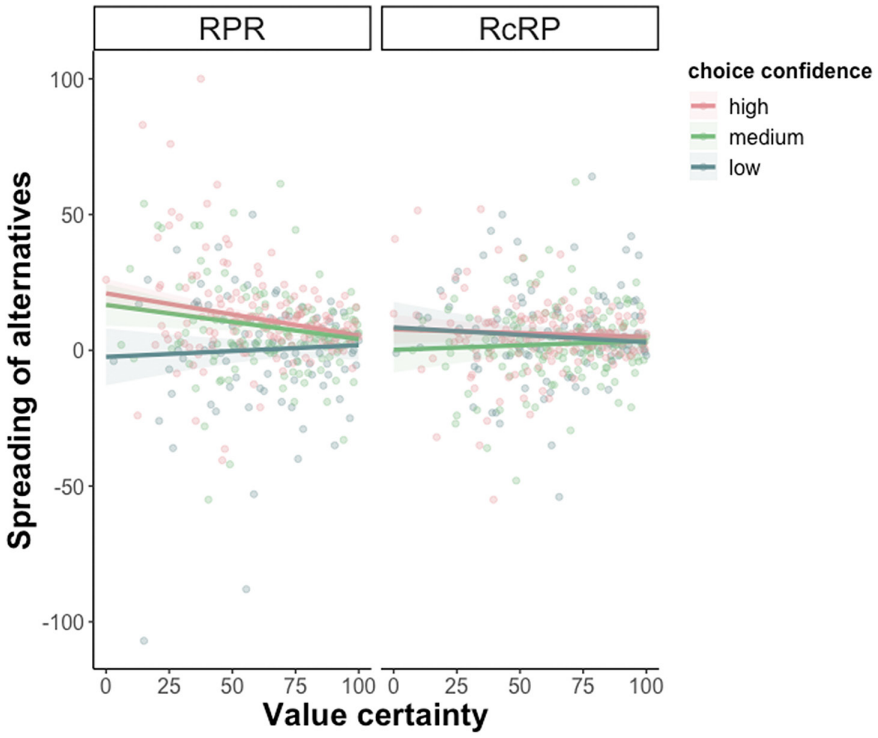

FIGURE 4 Evidence of value refinement in spreading of alternatives (SoA). Mean value certainty was negatively associated with SoA-RPR (SoA; ratings, preference choices, ratings) at medium- and high-confidence levels but not low-confidence levels. The associations between mean value certainty and SoA-RcRP (SoA; ratings, color choices, ratings, preference choices) were not significant at any level of choice confidence. Lines represent model estimates. Points represent the mean SoA at each unique level of mean value certainty and choice confidence. The shaded area represents 95% confidence intervals.

choice condition (RPR vs. RcRP), mean value certainty, and choice confidence (χ^2=6.01, p=.014). For post-hoc comparisons and visualization, we stratified choice confidence scores into three bands: low (≤33), medium (34–66), and high (≥67). This allows us to compare the impact of mean value certainty on SoA across levels of choice confidence, and between conditions. In the RcRP condition, there were no significant effects of value certainty on SoA for any level of choice confidence ($slope_{RcRP(low)}$=−.05, SE=.06, p=.393; $slope_{RcRP(medium)}$=.03, SE=.05, p=.536; $slope_{RcRP(high)}$=−.03, SE=.03, p=.351). For the RPR condition, lower mean value certainty was associated with higher SoA, only when participants reached a high or medium level of confidence in their choice, but not for low-confidence choices ($slope_{RPR(low)}$=.04, SE=.06, p=.542; $slope_{RPR(medium)}$=−.12, SE=.04, p=.010; $slope_{RPR(high)}$=−.14, SE=.03, p<.001). The association between value certainty and SoA when confidence was medium or high was significantly stronger in the RPR compared with the RcRP condition ($contrast_{RPR\text{-}RcRP(medium)}$=−.14, SE=.07, p=.027; $contrast_{RPR\text{-}RcRP(high)}$=−.12, SE=.04, p=.003). There was no difference between conditions for low-confidence choices ($contrast_{RPR\text{-}RcRP(medium)}$=.09, SE=.09, p=.304).

Taken together, these results support a value refinement account of SoA, showing SoA is largest when participants are initially uncertain about their values but resolve their uncertainty in a confident choice.

Value certainty increases after choice and second value ratings are more predictive of choice

If value refinement occurs during choices, we expect that: (1) value certainty will increase between the initial and second ratings and (2) the second value ratings will better predict preference choices than initial ratings. On average, value certainty increased between rating 1 and rating 2 (χ^2=7.00, estimate=.96, SE=.36, t=2.65, p=.008). Value certainty increased significantly more when participants completed preference choices between ratings (RPR) than when they completed color choices between ratings (RcRP) (rating-by-condition interaction: χ^2=4.42, p=.036; $contrast_{RPR\text{-}RcRP(rating1)}$=.12, SE=.51, p=.817, co ntrast$_{RPR\text{-}RcRP(rating2)}$=1.19, SE=.51, p=.019; prediction 1iii). Analyzed separately, both conditions alone showed a significant increase in value certainty between rating 1 and rating 2 ($contrast_{rating2\text{-}rating1(RPR)}$=2.03, SE=.36, p<.001, $contrast_{rating2\text{-}rating1(RcRP)}$=.96, SE=.36, p=.008).

In line with value refinement, when predicting preference choices (choose left) in the RPR condition, a model using the second set of ratings to calculate value difference (value rating left item minus value rating right item) provided a better fit than when using the first set of ratings to calculate value difference (Bayesian information criterion [BIC] rating 2=2229.9; BIC rating 1=2630.2; prediction 1iv).

When predicting preference choices that occurred after both ratings in the RcRP condition (in which we assumed there would be no value refinement), models using the initial rating value difference and second rating value difference should fit the data equally as well. To our surprise, we also found that the second rating value difference was a better predictor of choice than the first rating value difference in the RcRP condition (BIC rating 2 = 2366.0, BIC rating 1 = 2642.4). Taken together with the robust SoA-RcRP, these results raise the possibility that some value refinement may have occurred in the RcRP condition, either during ratings or during color choices. This is consistent with previous work showing that value refinement occurs during tasks other than preference choices (Lee & Holyoak, 2021).

Age-related differences in choice-induced preference change (Hypothesis 2)

Next, we tested our hypothesis that there would be an age-related decrease in value refinement through choice (H2). From this hypothesis, we made the following predictions: (i) there will be an age-related decrease in SoA-difference score, driven by a decrease in SoA-RPR, specifically a lower change in ratings when participants are initially uncertain but resolve their uncertainty in a confident choice; (ii) there will be an age-related increase in both initial value certainty and choice confidence; (iii) there will be an age-related decrease in the extent to which value certainty increased following choice.

SoA across age

When inspecting the SoA-difference score (RPR minus RcRP), we found a significant positive association with reciprocal age ($\beta = -206.25$, SE = 72.92, $t = -2.83$, $p = .005$; Figure 5, right panel). Thus, contrary to our prediction (2i), SoA due to value refinement showed an age-related increase (rather than decrease) across adolescence.

Further this age-related increase in SoA-difference score appeared to be driven by an age-related decrease in SoA-RcRP rather than an increase in SoA-RPR. There was a significant age-by-condition interaction (RPR vs RcRP) for SoA ($\chi^2 = 6.35$, $p = .012$; Figure 5, left panel). Post-hoc contrasts demonstrated a significant association between the reciprocal of age and SoA-RcRP but not SoA-RPR ($slope_{RPR} = -.74$, SE = 2.69, $p = .784$; $slope_{RcRP} = 8.00$, SE = 2.69, $p = .003$; $contrast_{RPR-RcRP} = -8.74$, SE = 3.5, $p = .012$). We further inspect this unexpected finding below.

Investigating age-related differences in preference change after color choices

To further investigate our unexpected finding that SoA-RcRP decreases over age, we conducted a number of exploratory analyses. There are a number of possible explanations for the age-related difference in SoA-RcRP. Here we provide additional analyses to investigate four possibilities, that age-related decrease in SoA-RcRP is due to: (1) age-related increase in attention to instructions; (2) age-related increase in variability of ratings and thus value

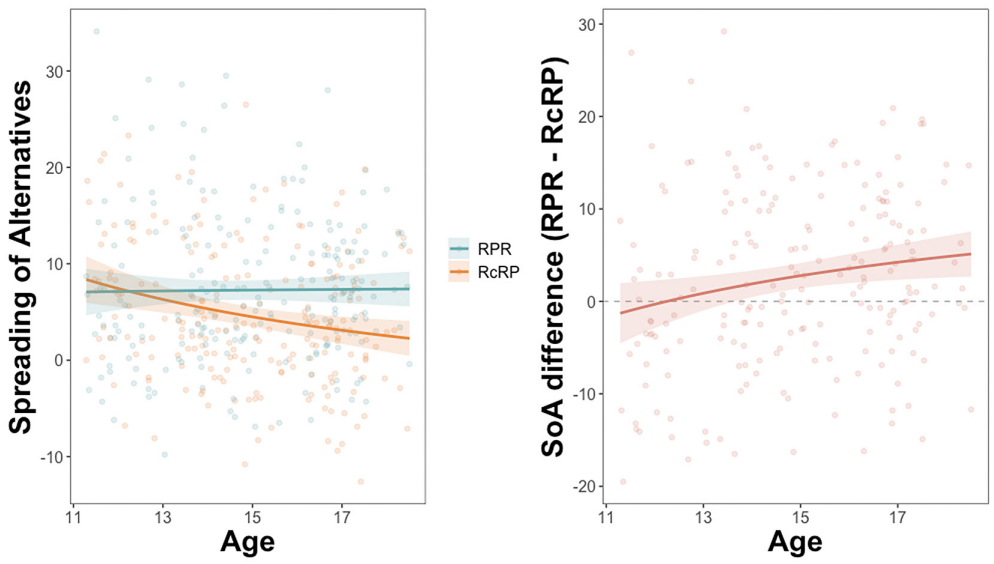

FIGURE 5 Age-related differences in spreading of alternatives (SoA). Left panel: SoA for activities in the ratings, preference choices, ratings (RPR) condition, and activities in the ratings, color choices, ratings, preference choices (RcRP) condition. Right panel: SoA-difference (SoA-RPR minus SoA-RcRP), that is, age-related difference in SoA after accounting for SoA in the control condition (driven by the statistical artifact). Lines show model estimates. Shaded areas show confidence intervals.

difference in choice pairs; (3) age-related difference in the effect of color choices for eliciting value refinement; (4) age-related decrease in overall noise in ratings.

We tested all four possibilities and found the most parsimonious evidence to suggest that the age-related decrease in SoA-RcRP is due to an age-related decrease in overall noise in value ratings (for details of tests for other possible explanations, see Supporting Information).

Greater noise in ratings (rather than noise in choices, see Izuma & Murayama, 2013) should lead to a larger SoA due to the statistical artifact (Figure 3). Indeed, the correlation between initial and second ratings showed an age-related increase (reciprocal age: $\beta = -2.54$, $t = -2.89$, $p = .004$). Further, age modulated the effect of value difference (rating 1; left item minus right item) on choice (choose left), which would be expected when initial ratings are noisier, albeit the interaction narrowly missed statistical significance ($\chi^2 = 3.82$, $p = .051$). If younger participants have a larger SoA due to the statistical artifact as a consequence of noisier ratings, this would affect both RcRP and RPR conditions. Since SoA-RPR does not show the same age-related decrease as SoA-RcRP, this implies that younger participants show (relatively) less SoA due to value refinement. This is also evident when inspecting the SoA difference score, which accounts for the component of SoA driven by noise in the ratings (Figure 5).

Value certainty and choice confidence across age

We next tested how both value certainty and choice confidence vary with age. We initially included age as an additional predictor along with value certainty and choice confidence in the model with SoA as the outcome. Through this, we could test whether age modulated the interaction between value certainty and choice confidence in the RPR condition. This tests whether older participants' show a decreased SoA when value certainty is resolved through choice. However, the four-way interaction between age (reciprocal), value certainty, choice confidence, and choice condition was non-significant ($\chi^2 = .21$, $p = .647$; prediction 2i).

Both value certainty and choice confidence exhibited a U-shaped association with age, rather than a linear increase (Figure 6; prediction 2ii). Accordingly, there was a significant association between the quadratic (but not linear) component of age and initial value certainty ($\chi^2 = 5.33$, $p = .069$; linear: estimate = 42.60, SE = 76.12, $t = .56$, $p = .576$; quadratic: estimate = 170.06, SE = 76.32, $t = 2.23$, $p = .027$; see Figure 6, left panel). The age-related difference in the extent to which value certainty was updated after choice in either condition was non-significant (age-by-rating interaction: $\chi^2 = 3.25$, $p = .071$; age-by-rating-by-condition interaction: $\chi^2 = 2.56$, $p = .120$; prediction 2iii).

There was a significant association between the quadratic (but not linear) component of age and choice confidence ($\chi^2 = 7.58$, $p = .023$; linear: estimate = 65.84, SE = 84.95, $t = .78$, $p = .439$; quadratic: estimate = 215.35, SE = 81.91, $t = 2.63$, $p = .009$; see Figure 6, right panel). There was no significant interaction between the linear or quadratic components of age and choice condition, showing a similar age-related difference in confidence for preference and color choices ($\chi^2 = .23$, $p = .889$; linear: estimate = 10.83, SE = 54.29, $t = .20$, $p = .842$; quadratic: estimate = 24.47, SE = 53.98, $t = -.45$, $p = .650$).

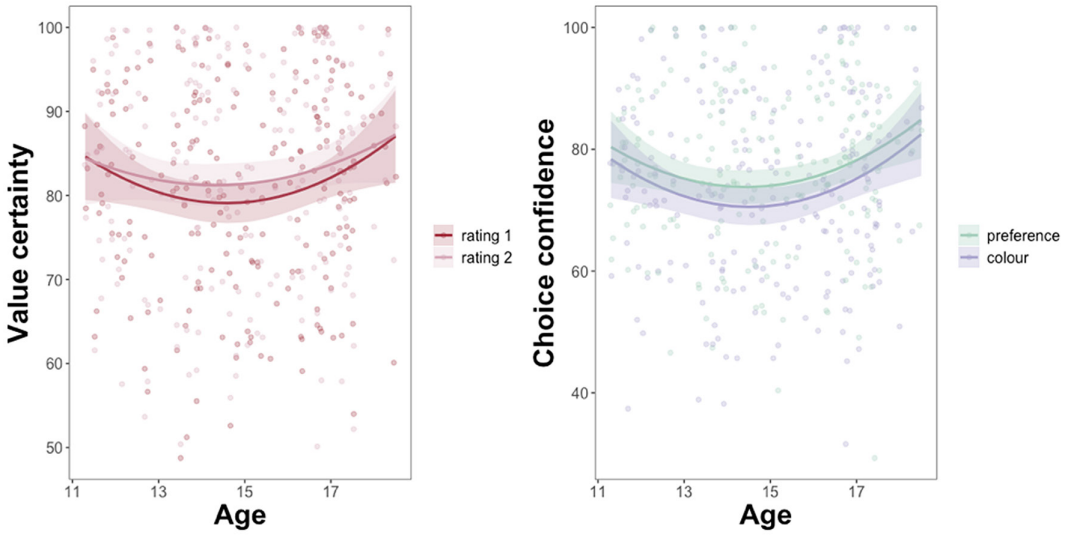

FIGURE 6 Age-related differences in initial value certainty and choice confidence. Left panel: Initial value certainty. Points represent individual participants' mean initial value certainty ratings in the first ratings. Right panel: Choice confidence. Points represent individual participants' mean confidence ratings in the second and final part of the task. Lines show model estimates. Shaded areas show confidence intervals.

Depression-related differences in choice-induced preference change (Hypothesis 3)

Next, we tested our hypothesis that adolescents with greater depressive symptoms would exhibit lower value refinement through choice than adolescents with fewer depressive symptoms (H3). From this hypothesis, we made the following predictions: (i) there will be a depression-related decrease in SoA-difference score, driven by a decrease in SoA-RPR, specifically a lower change in ratings when participants are initially uncertain but resolve their uncertainty in a confident choice; (ii) there will be a depression-related decrease in both initial value certainty and choice confidence; (iii) there will be a depression-related decrease in the extent to which value certainty increases following choice.

Scores on the MFQ-SF covered the entire range (0–26, $M = 7.80$, SD = 5.77). There were 54 participants who scored 12 or above, indicating possible depression. We report all associations with depressive symptoms continuously and by depression group (<12, ≥12).

SoA across depressive symptoms

The interaction between depressive symptom score and condition (RPR vs. RcRP) predicting SoA was non-significant ($\chi^2 = .69$, $p = .405$; $\text{contrast}_{\text{RPR-RcRP}} = .03$, SE = .03, $p = .405$). When isolating the effect of SoA from value refinement (i.e., mean SoA-RPR minus mean SoA-RcRP), there was no significant association between depressive symptoms and SoA (estimate = .63, SE = .72, $t = .88$, $p = .380$; prediction 3i).

When using categorical depression, the interaction between condition (RPR vs. RcRP) and depression group predicting SoA narrowly missed significance ($\chi^2 = 3.83$, $p = .057$; Figure 7, left panel). Post-hoc comparisons demonstrated that participants who met the clinical cut-off for depression showed a stronger SoA-RPR than those below the cut-off ($\text{contrast}_{\text{Depressed-Non-depressed(RPR)}} = .23$, SE = .06, $p < .001$). There was no difference between the groups on SoA-RcRP ($\text{contrast}_{\text{Depressed-Non-depressed(RcRP)}} = .08$, SE = .06, $p = .207$). Additionally, and contrary to our hypothesis, participants who scored above the clinical cut-off had a higher SoA-difference than those scoring below the cut-off (estimate = 3.81, SE = 1.67, $t = 2.28$, $p = .023$; Figure 7, right panel; prediction 3i).

In summary, depressive symptoms analyzed continuously were not associated with SoA. When analyzed categorically (below and above clinical cut-off), participants who met the clinical cut-off showed a stronger SoA due to value refinement.

Value ratings, certainty, and choice confidence across depressive symptoms

To further investigate depression-related differences in SoA, we assessed whether depressive symptoms modulated the interaction between value certainty and choice confidence on SoA-RPR (prediction 3i). There was a significant four-way interaction between choice condition (RPR vs. RcRP), choice confidence, value certainty and depressive symptom score, as well as between these three predictors and depression group in the categorical analysis (depressive symptom score: $\chi^2 = 10.91$, $p < .001$; depression group: $\chi^2 = 10.36$, $p = .001$). We again used stratified confidence scores (low, medium, high) to investigate post-hoc comparisons. In the RPR condition, the modulation of the association between value certainty and SoA by choice confidence was greater in the depressed group. This was most evident in high- and low-confident choice trials ($\text{contrast}_{\text{Depressed-Non-depressed(RPR,low)}} = .47$, SE = .14, $p < .001$; $\text{contrast}_{\text{Depressed-Non-depressed(RPR,medium)}} = .16$, SE = .11,

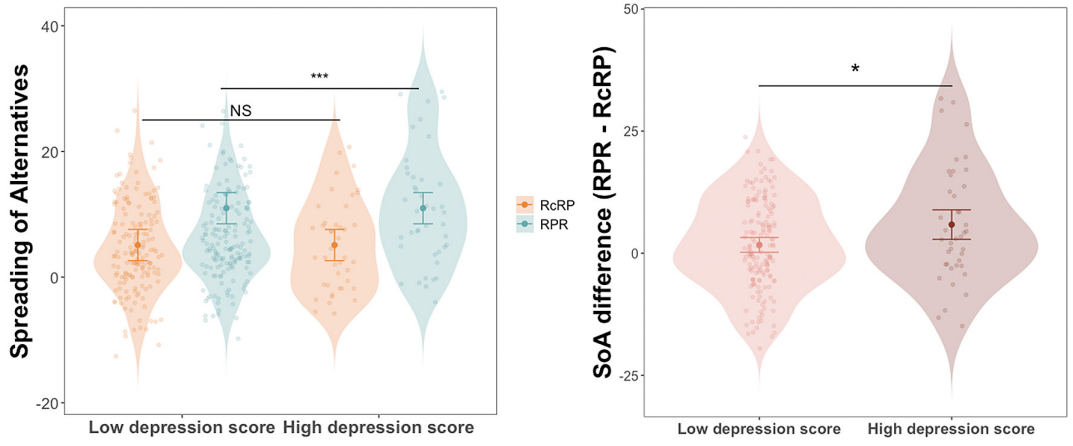

FIGURE 7 Depression-related differences in spreading of alternatives. Low depression score indicates participants scoring below 12 on the mood and feelings questionnaire—Short Form. High depression score indicates participants scoring 12 or above. Points indicate participant means. RPR, ratings, preference choices, ratings; RcRP, ratings, color choices, ratings, preference choices. Error bars show 95% confidence intervals. *$p < .05$, ***$p < .001$, NS, non-significant.

$p = .123$; $\text{contrast}_{\text{Depressed-Non-depressed(RPR,high)}} = .13$, SE = .06, $p = .046$). In other words, depressive symptom score was associated with a greater SoA after value refinement (value uncertainty resolving in a confident choice). Neither group showed an association between value certainty and SoA-RcRP at any level of confidence.

There was a significant association between depressive symptoms and initial value certainty, whereby participants with greater depressive symptoms reported less certainty about their value judgments ($\chi^2 = 6.72$, estimate = −2.25, SE = .87, $t = -2.59$, $p = .010$; Figure 8, left panel; prediction 3ii). Despite increased value refinement in depressed adolescents, depressive symptoms were associated with lower value certainty updating across both conditions (rating-by-depressive symptom score interaction: $\chi^2 = 4.28$, $p = .039$; prediction 3iii) but this was not modulated by condition (rating-by-condition-by-depressive symptom score interaction: $\chi^2 = .07$, $p = .795$).

Participants with greater depressive symptoms also reported lower choice confidence overall (main effect of depressive symptoms: $\chi^2 = 7.30$, estimate = −2.99, SE = 1.10, $t = -2.70$, $p = .007$; Figure 8, right panel; prediction 3ii). The interaction between depressive symptoms and choice type (preference vs. color) was non-significant ($\chi^2 = 1.73$, $p = .188$), suggesting that depressive symptoms were associated with a global reduction in choice confidence.

In summary, depressive symptoms were associated with greater updating of value ratings (SoA) when value refinement had occurred during preference choices (low initial value certainty resolved in a high-confidence choice). Depressive symptoms were also associated with lower initial value certainty, lower updating of value certainty across all activities, and lower preference and color choice confidence. Therefore, despite depressed adolescents demonstrating a greater SoA, depressive symptoms were associated with lower updating of value certainty following choice and lower choice confidence.

When considering depression categorically (MFQ-SF cut-off score of 12), the above associations with value certainty, certainty updating, and preference/color choice confidence were no longer apparent (value certainty: $\chi^2 = 1.34$, $p = .247$; overall value certainty updating: $\chi^2 = 2.21$, $p = .137$; choice confidence: $\chi^2 = 1.54$, $p = .214$).

Finally, we tested whether depression was associated with lower reported enjoyment of the activities, but neither depressive symptoms nor depression group were associated with value ratings (symptoms: estimate = −.07, SE = .13, $t = -.52$, $p = .603$; group: estimate = .90, SE = 1.69, $t = .53$, $p = .596$).

DISCUSSION

We investigated a potential mechanism of self-concept development, namely adolescents' ability to use choice to update and refine their preferences. Adolescents displayed a substantial choice-induced preference change, updating their value ratings and value certainty after preference choices. Importantly, the observed SoA occurred over and above that expected from a statistical artifact account (Chen & Risen, 2010). We replicated previous findings supporting a value refinement account of choice-induced preference change. Specifically, larger SoAs occurred when participants could confidently choose between closely rated activities that they were initially less certain about, providing further evidence that preference change occurs as a result of choice deliberation. The same pattern of results was not observed when preference choices did not occur until after all ratings had been made.

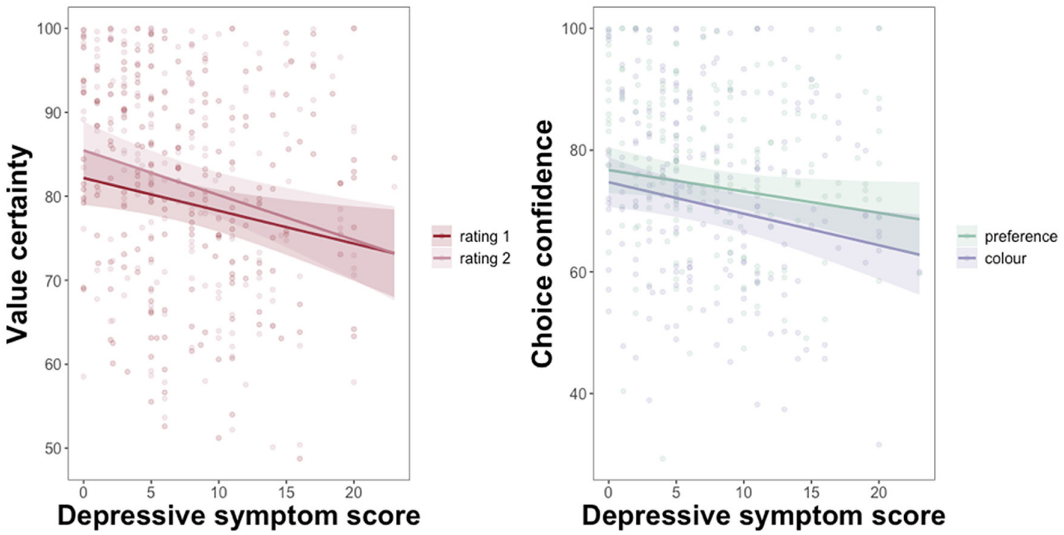

FIGURE 8 Depression-related differences in value certainty and choice confidence. Depressive symptoms were associated with lower initial value certainty and lower choice confidence (across part two and part four, in preference and color choices).

Once accounting for SoA resulting from statistical artifact, we demonstrated an age-related increase in adolescents' ability to update and refine their preferences through choice. Participants under the age of 14 showed very little value refinement, which increased across the older age range. Reported value certainty and choice confidence showed an age-related U-shaped association, with younger participants and older participants reporting higher certainty in value ratings and choices (both preference and color) than participants in the middle of the age range. Participants scoring above the clinical cutoff on the depression scale had a larger SoA due to value refinement, with larger updates in their value ratings when resolving initial uncertainty during choice. Despite this, participants with greater depressive symptoms reported lower initial value certainty, which remained low during the second ratings, and lower choice confidence across all choices (although this pattern was not evident when considering depression categorically). We discuss the implications of our results for adolescent self-concept development, in light of increased mental health risks.

Adolescence is marked by a growing sense of independence and autonomy. Across adolescence, young people are often given more opportunities to be unsupervised by adults and explore their environment, which expands their decision-making space. This is frequently accompanied by increased novelty seeking, risky decision making, and resistance to authority. These behaviors allow adolescents to learn about themselves and their environment in the face of uncertainty. However, this period is also characterized by prolonged maturation of decision-making abilities, including the ability to reflect on choices (Moses-Payne et al., 2021; Weil et al., 2013) and to resist influence from others (Roebers, 2002; Roebers & Howie, 2003; Schwarz & Roebers, 2006). These findings motivated our interest in understanding age-related differences in adolescents' ability to learn about their preferences through choice.

Overall, we found that adolescents across the ages of 11–18 were able to use choice to refine their preferences, updating their value ratings and increasing value certainty after making preference choices. The addition of value certainty and choice confidence ratings to the task design allowed us to replicate previous work supporting the value refinement explanation of SoA. We showed that SoA was stronger when participants were asked to make decisions between activities they were initially less certain about but, after deliberation, managed to confidently choose between. This pattern of result supports the notion that SoA reflects, at least in part, a process of choice deliberation and value refinement.

Interestingly, we found that younger adolescents showed a greater SoA for activities in the control (RcRP) condition, where preference choices were not made until all ratings were complete. This SoA-RcRP is expected to arise from Chen and Risen's (2010) "statistical artifact" account, which rests on key behavioral and methodological features of the free-choice paradigm. It proposes that participants' value ratings are noisy and that preference choices at least partially reflect participants' true preferences. In order to maximize the potential for SoA, the task design required that closely rated activities be paired. However, this also increases the likelihood that the statistical artifact will arise if the ratings are drawn from the edges of their true value distributions (i.e., if they are especially impacted by noise). We concur that this is a convincing explanation of SoA-RcRP but it is still interesting to understand the cognitive influences on the SoA in the absence of preference choice. We suggest that the age-related decrease in SoA-RcRP demonstrated here could reflect younger adolescents' greater uncertainty about their own preference ratings, increasing noise in their ratings. Therefore, the consequent heightened SoA-RcRP in early adolescence is likely reflective of processes that relate to the statistical artifact, but which themselves may derive from important developmental changes that occur during this period. These developmental changes could be related to the capacity for young people to judge activities in the task and make ratings (to hold and weigh multiple attributes of the activities and combine these to make a single value judgment), or alternatively/additionally could be due to greater experience with the activities in the task, both of which would decrease rating uncertainty/noise. As this is expected to affect both SoA-RcRP and SoA-RPR, we next aimed to isolate the effect of SoA due to true value refinement.

Our study employed a design that allowed us to isolate the SoA effect resulting from value refinement. Specifically, we calculated within-participant difference scores by subtracting each subject's SoA in the absence of preference choices between ratings (SoA-RcRP) from their SoA due to preference choice deliberation (SoA-RPR). This enabled us to investigate the isolated SoA effect specifically resulting from value refinement, which showed an age-related increase. Interestingly, previous research has suggested that the ability to accurately reflect upon choices exhibits a similar developmental pattern, potentially emerging in early adolescence (Fandakova et al., 2021; Moses-Payne et al., 2021). We speculate that this lesser ability to reflect on choices, coupled with increased uncertainty about their subjective value of different activities and the decision-making process, may have hindered younger participants' ability to learn during choice deliberation and adjust their values accordingly. Future work should measure both of these cognitive faculties and examine their potential relationship.

We also conducted supplementary analyses to explore alternative explanations of the observed age-related differences in SoA. One possibility is that value refinement can occur not only during preference-based choices but also during deliberation over non-preference-based choices, for example, the color

choices included here (Lee & Holyoak, 2021). Our findings provided some evidence supporting this possibility. Specifically, in the RcRP condition, where no value refinement is expected to occur (according to a statistical artifact account), we observed an increase in value certainty between ratings and found that second value ratings were a better predictor of choice than initial ratings. This raises the possibility that simply being faced with choice alternatives (even without preference-based instructions) may stimulate some value refinement. Therefore, it is possible that value refinement also occurred during the color choices and that the age-related decrease in SoA-RcRP was due in part to the age-related decline in value refinement during color choices. However, we tested a number of predictions derived from this hypothesis but did not find any evidence to support it. Nevertheless, future studies may consider including an additional control condition in which color choices are removed, to more accurately assess SoA resulting from the statistical artifact. If value refinement indeed occurred in the RcRP condition, we would expect that removing color choices from the control condition would make the age-related increase in SoA difference scores even more pronounced.

Interestingly, we found that the noise present in the value ratings of younger adolescents was not reflected in their subjective reports of uncertainty. Instead, both younger and older adolescents reported the greatest certainty in their initial value ratings. The same U-shaped developmental pattern was also observed for confidence judgments in both preference and color choices. In contrast, there was no age-related difference in value rating updating on trials where initial value certainty was resolved in a highly confident choice. The motivation to seek information and resolve uncertainty in our preferences through choice depends on the ability to accurately estimate and monitor uncertainty (Gottlieb et al., 2013). If younger adolescents were overly certain about their value estimates, their motivation to resolve uncertainty through choice may have been reduced, which could explain why they showed lower value refinement. This is consistent with previous research suggesting that late childhood and early adolescence are associated with inflated metacognitive judgments of performance (Moses-Payne et al., 2021; van Loon et al., 2017; Was & Al-Harthy, 2018). However, results are mixed, with different paradigms producing different developmental patterns of metacognitive judgments (Brackmann et al., 2019; Fandakova et al., 2021). This is likely influenced by differences in the underlying performance itself (Fleming & Lau, 2014), reducing the ability to decouple metacognitive judgments from task performance. This limitation is shared by our study, as there is no "ground truth" or accuracy in value-based decisions. Therefore, our results point to an interesting avenue for future research: to assess developmental changes in adolescents' ability to monitor uncertainty and generate strategies for reducing uncertainty. However, this may be best assessed in non-value-based decisions, where changes in task performance can be matched across age and decoupled from metacognitive performance.

It is well established that adolescence is a period of increased risk for the onset of mental health conditions (Kessler et al., 2007; Solmi et al., 2022). One potential area for intervention is the development of self-concept, as negative self-appraisals and increased uncertainty in self-concept have been linked to the development of depressive symptoms (Mullarkey et al., 2019; Orth et al., 2008; Rieger et al., 2016). By understanding how adolescents construct their sense of self, we may be able to help young people develop a positive and stable self-concept during this time of change. We found that adolescent depressive symptoms were associated with lower certainty in value ratings, lower updating of value certainty after choice, and lower choice confidence, which aligns with previous findings that depressive symptoms are negatively associated with confidence in adults (Rouault et al., 2018); albeit this pattern was not observed when treating depression categorically.

Interestingly, participants scoring over the MFQ-SF cut-off for depression had an apparently intact SoA due to value refinement. In fact, categorically defined depression was associated with greater SoA on trials where initial value uncertainty was resolved in a confident choice. These findings may indicate that depressive symptoms are associated with decreased subjective reports of certainty and confidence in the presence of an intact value refinement mechanism. In other words, depressed adolescents were able to use choice to reassess their value estimates but nonetheless remained less confident in their choices and less certain about their value ratings in spite of this. This might suggest a potentially fruitful avenue for intervention in depression in adolescence, targeting adolescents' feelings of certainty and confidence in their decisions rather than targeting decision making per se. It would also be interesting to investigate whether these alterations in confidence are related to a reduction in seeking real-world autonomic choices, given that depressed adolescents may not experience the same (rewarding) reduction in uncertainty from independent choice as healthy adolescents. However, longitudinal designs are needed to ascertain whether these differences in certainty and confidence are a risk factor for depression or simply reflect the presence of symptoms.

The current study has several limitations. First, these findings, when considered in isolation, do not definitively eliminate the possibility that cognitive dissonance plays a role in SoA. It is plausible that both cognitive dissonance and value refinement could be acting simultaneously to create SoA, as the accounts are not entirely mutually exclusive. Consequently, an

alternative interpretation of the results is possible: either the experience of cognitive dissonance intensifies during adolescence or becomes more likely with age, possibly due to changes in counterfactual thinking and emotions (e.g., regret, relief) across adolescence (Palminteri et al., 2016; Rodrigo et al., 2018), or the experience of cognitive dissonance is stable but the impact of cognitive dissonance on value ratings grows stronger throughout adolescence. Depressed participants may also experience greater cognitive dissonance after making choices or may change their ratings further in response to cognitive dissonance. This would fit with previous findings showing that, in adults, depression was associated with a greater reduction in confidence following further counterfactual evidence (as well as a greater increase in confidence following decision-congruent evidence; Moses-Payne et al., 2019). Therefore, future work may wish to investigate the role of counterfactual thinking as well as basic logical abilities in the development of SoA. It also remains unclear whether SoA is a deliberative process or whether the change in ratings occurs without participants' awareness, further investigating the impact of individual differences in memory abilities may be able to elucidate this. Second, the population tested in this study was specific, as all young people were recruited from schools across London. Therefore, the sample characteristics may play an important role in the observed effects (although, within our sample, socioeconomic status and ethnicity did not have any detectable impact on the findings). Future work should aim to generalize the findings across different communities, countries, and cultures. Finally, although the majority of tests were hypothesis-driven, we included a number of exploratory analyses to investigate the age-related decrease in SoA in the color condition, which may be vulnerable to an increased risk of false positives.

In summary, we find that independent decision-making in adolescence may be an important means of refining and developing a self-concept. We found that this ability emerges during adolescence, with older adolescents potentially more able to use choice to refine their value estimates. Depressive symptoms were associated with greater refinement of values during choice deliberation. Despite this, more depressed adolescents remained less certain about their preferences and were less confident in their choices. Future work should build on these results to further our understanding of the processes involved in self-concept formation in adolescence, including how these processes are influenced by depressive symptoms, which would enable more effective support to promote a healthy self-concept during this critical development stage.

AUTHOR CONTRIBUTIONS

MEMP, DGL, and JPR designed the study. MEMP wrote the manuscript with assistance from DGL and JPR. MEMP collected and analyzed data with guidance from DGL. This work has been seen and reviewed by all authors.

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CONFLICT OF INTEREST STATEMENT

The authors declare no competing financial interests.

DATA AVAILABILITY STATEMENT

The data and code necessary to reproduce the analyses presented here are publicly accessible, as are the materials necessary to attempt to replicate the findings. Analyses were not pre-registered. Data, code, and materials are available on request from the corresponding author.

ETHICS STATEMENT

The study was approved by the UCL Research Ethics Committee (Project ID: 14261/001).

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SUPPORTING INFORMATION

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