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Opening the cuebox: The information children and young adults generate and rely on when making inferences from memory

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We used a cue-generation and a cue-selection paradigm to investigate the cues children (9- to 12-year-olds) and young adults (17-year-olds) generate and select for a range of inferences from memory. We found that children generated more cues than young adults, who, when asked why they did not generate some particular cues, responded that they did not consider them relevant for the task at hand. On average, the cues generated by children were more *perceptual* but as informative as the cues generated by young adults. When asked to select the most informative of two cues, both children and young adults tended to choose a *hidden* (i.e., not perceptual) cue. Our results suggest a developmental change in the cuebox (i.e., the set of cues used to make inferences from memory): New cues are added to the cuebox as more cues are learned, and some old, perceptual cues, although informative, are replaced with hidden cues, which, by both children and young adults, are generally assumed to be more informative than perceptual cues.

How do people make inferences, such as which of two cars is more expensive? In many inference situations, often the first thing to do is to collect information about the various options – In this case, about the two cars. For example, people might look up how fast the two cars are, their horsepower, or their fuel consumption per kilometre. This information-gathering process in the real world is very often self-directed (Hau, Pleskac, Kiefer, & Hertwig, 2008; Hills & Hertwig, 2010; Markant & Gureckis, 2012), meaning that people can decide what and how much information to collect, and in what order.

Children and adults' pre-decisional information search has traditionally been studied in a cue-selection paradigm, where participants can select which pieces of information (i.e., cues) to look up from a list of given cues. We looked at the cues children and young adults have available when making inferences from memory by having them recall and generate cues, rather than presenting them with a list of cues. The cue-generation methodology allowed us to investigate the types of cues children and young adults spontaneously

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generate when making inferences from memory. Moreover, we examined how the type of cues influences children's and young adults' ability to generate or select the most informative cue.

Children's pre-decisional information search in a cue-selection paradigm

In previous studies on children's cue-based decision-making, researchers implemented an information-board procedure (Davidson, 1991a,b, 1996; Gregan-Paxton & John, 1995, 1997; Howse, Best, & Stone, 2003; Mata, von Helversen, & Rieskamp, 2011). An information board consists of a matrix of values: The rows represent the choice or decision alternatives, which can be two or more (e.g., Comb A and Comb B); the columns contain information related to a cue (e.g., size); and the matrix cells are cue values. For example, at the intersection of the row 'Comb A' and the column 'Size' is Comb A's size, for example 'too small' (example taken from Howse *et al.*, 2003). Before children choose an alternative, they have the possibility of exploring the information board, selecting and examining whatever pieces of information they want, in any order.

This line of research shows that younger children (i.e., second graders) are less systematic in their information search than older children (i.e., fifth graders) and – when search comes at no cost – tend to gather more information than older children (Gregan-Paxton & John, 1995, 1997). Older children are more likely than younger children to base their decision on the same two or three cues (e.g., the colour and the cost of a bicycle, Davidson, 1991a,b), focusing on the dimensions defined in the cover story as most relevant, whereas younger children tend to focus on irrelevant information more often (Davidson, 1991b; Hagen & Hale, 1973; Pick & Frankel, 1973). However, Mata *et al.* (2011) found that in a cue-based inference task, even older children are often not able to implement frugal strategies, that is, strategies that employ only one or a few cues (Gigerenzer, Todd, & the ABC Research Group, 1999). Beyond this general developmental tendency, both younger and older children's information search strategies are sensitive to different characteristics of the task, such as the amount of information available (Davidson, 1991a), the number of alternatives to be evaluated (Katz, Bereby-Meyer, Assor, & Danziger, 2010), the presence of a memory aid (Davidson, 1991b; Katz *et al.*, 2010), the complexity and demands of the task (Bereby-Meyer, Assor, & Katz, 2004), the search costs (Howse *et al.*, 2003), and the environmental probabilities (Nelson, Divjak, Gudmundsdottir, Martignon, & Meder, 2014).

The cue-generation paradigm

The information board used in cue-based decision-making research is appropriate for investigating what strategies children use when searching for information and how well children adapt their search for information to different task characteristics. However, information boards require researchers to predetermine the cues to be made available for the search. Thus, using a cue-selection paradigm severely limits the conclusions that can be drawn about the cues children spontaneously generate when making real-world inferences.

In addition to possibly not including all the information a child could think of, the cue-selection paradigm requires children to assess and compare the informativeness of exogenously given cues they might not be familiar with, or the meaning of which they might not even know, such as horsepower (Ruggeri & Katsikopoulus, 2013). Moreover, researchers in cue-based decision-making often ask children to take the perspective of another child (e.g., Davidson, 1996; but see Davidson, 1991b, for an exception), or, especially when testing adults, they use tasks with cover stories that minimize reliance on real-world knowledge and present situations that are likely unfamiliar to most participants (e.g., Bröder & Schiffer, 2003; Gigerenzer *et al.*, 1999; Mata *et al.*, 2011; Rakow, Newell, Fayers, & Hersby, 2005; Rieskamp & Otto, 2006; but see Pachur, Bröder, & Marewski, 2008, for an exception). In this way, researchers try to design experiments that rule out the experience children and adults have with particular cues, the preferences they might have for some types of cues, and their intuition about the informativeness of cues in an inference task. For children, even more than for adults, it might be hard to ignore their previous experience and adapt their information search to what is exogenously defined as relevant or informative.

An alternative to using the information board to study children's pre-decisional information search is to implement a *cue-generation* methodology, which allows children to generate their own cues by asking questions about anything they deem relevant for making the inference at hand. The process of asking questions from scratch has been thoroughly studied (Graesser & McMahen, 1993; Graesser & Olde, 2003), also as a mechanism for cognitive development and knowledge acquisition (Chouinard, 2007; Vosniadou, 1994). This methodology has also been used to investigate search for information in categorization tasks (Mosher & Hornsby, 1966; Ruggeri & Feufel, 2015; Ruggeri, Lombrozo, Griffiths, & Xu, 2015), causal reasoning tasks (Ruggeri & Lombrozo, 2014, 2015), and preferential choice tasks (Katz *et al.*, 2010). However, to the best of our knowledge, it has been used to research cue-based decision-making inferences only once (Ruggeri & Katsikopoulus, 2013).

Ruggeri and Katsikopoulus (2013) tested 7-year-olds, 9-year-olds, and young adults (17-year-olds) on two problems (which of two real cars is more expensive and which of two real cities has more inhabitants). The study manipulated how participants obtained cues, that is whether cues had to be selected or whether participants had to generate their own, by asking anything they wanted about the objects (e.g., cities) they had to make inferences about. Participants received no instructions or training on what cues should be considered more relevant or informative. However, the informativeness of the generated cues was objectively assessed as the probability of that cue leading to a correct inference in that particular task. The authors found that, when allowed to generate their own cues, 7-year-olds matched 9-year-olds and young adults in accuracy, or even outperformed them. On the other hand, when cues were given, children were less accurate than young adults. One possible interpretation of this result is that the cues generated by children, although different from those generated by young adults, were as informative or sometimes even more informative. Children, however, were not able to identify the most informative cues in a given set.

The present studies

In four studies, we used both a cue-generation and a cue-selection paradigm to investigate the cues children (9- to 12-year-olds) and young adults (17-year-olds) generate and select when making inferences from memory. In this research, we attempted for the first time to 'open' children's and young adults' *cueboxes*, which we define as the set of cues a person has available to recall and generate when making an inference.

In particular, in Studies 1 and 2 we examined the number, informativeness, and type – perceptual versus 'hidden-property cues' (hereafter referred to as 'hidden') – of cues our participants generated for a range of everyday inference tasks. In Study 2, we tested alternative interpretations of the developmental effects found in Study 1, analysing the generation task as a sequential filtering process involving knowledge (i.e., availability of the cues), memory (i.e., ability to recall the known cues), and a relevance judgment (i.e., deciding which cues are relevant for the task at hand).

In Study 3, we asked participants to generate what they deemed the single most informative cue for each of the inference tasks used in Study 1. Our goal here was to investigate whether children and young adults differ in the ability to select the most informative among the cues in their cuebox.

In Study 4, we investigated how children's and young adults' assumptions about the informativeness of a certain type of cue can influence the cue-selection process. We asked participants to select the most informative of two given cues, for two different inference tasks.

STUDY I

In Study 1, we explored the contents of the cuebox by asking children and young adults to generate all the cues they would like to know about, for a range of inference problems. We assumed that the number of cues participants generated would be strongly constrained by the number of cues they *have available*, that is by the number of cues they are aware of and have experienced as related to the task at hand. On the basis of this assumption, we expected children to generate fewer cues than young adults, because they might not know of some of the more technical cues we learn later in life (e.g., horsepower, or density of population).

We hypothesized that the results of Ruggeri and Katsikopoulus (2013) would be replicated. We expected children and young adults to generate cues that, although different, were equally informative. To check the robustness and generalizability of those results, we extended the cue-generation paradigm to include 10 additional inference tasks (for a total of 12 tasks).

We expected children to generate a greater proportion of *perceptual* cues than young adults. Perceptual cues refer to observable, obvious features of the objects (such as the length of a car). *Hidden* cues, in contrast, refer to underlying and potentially more technical or abstract features of the objects that are not obvious (such as a car's horsepower, see Gelman, 2003; Gelman & Markman, 1986, 1987; Gopnik & Sobel, 2000; Keil, 1989; Keil & Batterman, 1984; Nazzi & Gopnik, 2000; Newman, Herrmann, Wynn, & Keil, 2008).

First, children are novices in most domains of inference, and perceptual cues are the first learned because they are the most obvious and salient. Therefore, most of the cues children have available for making inferences from memory might be perceptual cues. Second, although young children are already able to use both perceptual and non-perceptual (hidden) features in categorization and inference tasks (Gelman & Markman, 1987; Gopnik & Sobel, 2000; Keil, 1989; Wellman & Gelman, 1988), they tend to spontaneously focus on perceptual, visible, and highly salient properties, for example grouping objects according to perceptual similarity (Gelman & Davidson, 2013; Gentner, 2010; Keil & Batterman, 1984). Only later children start to consider hidden properties and, for example, group objects based on more elaborate cues such as labels and shared internal properties (Carey, 1985; Keil, 1989; Medin, 1989; Rips, 1989).

Materials and methods

Participants

Participants in Study 1 were 47 children in the fourth and fifth grade (22 female, M_{age} = 9.33 years, *SD* = 0.62) and 51 young adults (44 female, M_{age} = 17.42 years, *SD* = 0.83) from two schools in Livorno, Italy. The students were all Italian and belonged to various social classes.

Design and procedure

The experimental session consisted of a paper-and-pencil questionnaire, collectively administrated in class, composed of eight questions presented on separate sheets, all describing similar problems, such as, 'There are two cars, Car 1 and Car 2, both currently produced by Fiat. Let us suppose you have to guess which of these two cars is faster. What would you like to ask about them before making the decision?' In every problem, we also specified the reference class, that is the set of objects that would be considered for calculating the informativeness of the generated cues (e.g., the 56 models of cars currently produced by Fiat). For each task, participants had 5 min to generate all the cues they could think of that could help them make that inference.

We had 12 problems in total that differed in terms of the objects presented and the inference problem participants were asked about (Table 1). The problems were randomly assigned to the participants and presented in a different random order for each participant. Participants were repeatedly prompted to generate as many cues as they

Table 1. Inference tasks presented to the participants in Studies 1, 2, and 3

Abbreviation	Inference task
City population	Which of these two cities, taken from the 60 most populous Italian cities, is more populous?
Car price	Which of these two cars, taken from the ones currently produced by Fiat, is more expensive?
Cell phone price	Which of these two cell phones, currently sold by Media Market, is more expensive?
Actor earn	Which of these two actors, among the 20 actors who earned the most in 2010, earned more money last year?
Team results	Which of these two soccer teams from the Italian first league will win the match?
Movie earn	Which of these two movies, among the 20 films that brought in the most in 2010, brought in more money?
Player earn	Which of these two soccer players, among the 20 players who earned the most in 2010, earns more money per month?
Animal speed	Which of these two animals, which you could find in Pistoia's Zoo, is faster?
City temperature	Which of these two cities, taken from the 60 most populous Italian cities, has on average the higher temperature?
Car speed	Which of these two cars, taken from the ones currently produced by Fiat, is faster?
House price	Which of these two houses, currently on sale in Ardenza[a], is more expensive?
Book sales	Which of these two books, taken from the 60 books held by most libraries in the world, sold more copies?

Note. [a]A neighbourhood of Livorno.

could, and they were told that all the students completing the tasks 'to the best of their ability' would be rewarded with a prize – A box of coloured pencils for the children and a USB stick for the young adults. All experimental procedures were approved by the ethics committee of the Max Planck Institute for Human Development, and all the parents, as well as the teachers, of the children involved were informed in advance and agreed to let the children participate.

Coding the type of cues

The distinction between perceptual and hidden features has been used and thoroughly investigated in previous research. However, in previous developmental studies, perceptual features are indeed observed, not just *observable*. For the scope of this paper, we realize that the conceptualization of perceptual and hidden cues derived from previous research is not clear and specific enough, making it difficult to trace the categories' boundaries.[1] Thus, we decided to operationalize the definition of perceptual and hidden cues empirically.

We asked an independent Italian sample of 20 children (9 female, M_{age} = 8.85 years, SD = 0.37) and 20 young adults (11 female, M_{age} = 17.9 years, SD = 1.43) to categorize all the cues included in the analysis as either perceptual, defined as cues that are observable, or hidden, defined as cues whose values cannot be simply observed. The reliability of the results of these 40 independent categorizations was high (intraclass correlation coefficient = .91). For each cue, we calculated the percentage of participants rating it as perceptual. When this proportion was higher than 70%, the cue was coded as perceptual; when the percentage was lower than 30%, the cue was coded as hidden. Eight cues, for which the percentage of participants' ratings was between 30% and 70%, were coded as 'uncertain'. Table S1 of the Supporting information reports the percentage of participants' ratings and the final categorization of the cues. A more stringent threshold (80% and 20%) would not have changed the magnitude of our results.

As a result of this categorization, the definition of perceptual cues encompasses (1) clearly perceptual cues (such as length, size, height, etc.), whose values are evident at a glance, as well as (2) cues whose values can be observed only when looking in a specific direction (e.g., gears that can be observed only by getting into the car), and (3) cues whose values can be estimated through experience and active search (e.g., number of museums, illustrations in a book). In contrast, the definition of hidden cues encompasses all cues whose values you cannot be directly perceived, whose values have to be obtained from an external source (e.g., horsepower, years of experience of a player).

Calculation of informativeness

We built a data set for each of the 12 inference tasks used in Study 1. Each data set included (1) all objects included in the reference classes defined for the 12 inference tasks (e.g., the 60 most populous Italian cities, see Table 1); (2) the criterion value for each object, that is what participants had to make inferences about (e.g., the number of inhabitants, see Table 1); and (3) the value of each object (e.g., city) for each of the cues generated by

[1] *We are grateful to an anonymous reviewer for stressing the importance of the conceptual definition of perceptual and hidden cues.*

participants (Table S1). The information needed to complete our database was found online: Our sources for official databases and statistics are listed in Table S2.

We considered the average informativeness of all cues generated by each subject for each inference task. The informativeness of the generated cues was measured in terms of success (Newell, Rakow, Weston, & Shanks, 2004). The success of a cue in a two-alternative forced-choice inference task is the probability, in that particular inference task (i.e., considering the objects of the specified reference class), that the cue will lead to a correct inference. All generated cues, when possible, were interpreted as referring to continuous values (e.g., number of other books published, number of airports, area of the city, number of cameras).

Results

Number of cues

In total, participants in Study 1 generated 3,962 cues. Children generated on average 6.1 cues per trial (SD = 2.72), whereas young adults generated on average 4.5 cues per trial (SD = 1.83). Because part of our research focused on the objective informativeness of the cues generated by participants, we asked two adults, blind to the experimental hypotheses and to the tasks, to independently exclude (1) the subjective cues, that is cues whose values (and therefore informativeness) could not be objectively assessed. Examples of such cues are 'is the actor/soccer player beautiful' (generated by 104 children, 14 young adults), or 'how nice is the soccer player/actor/animal' (generated by 130 children, 17 young adults); (2) the cues whose values related to our reference class were not assessable, such as 'did one of the teams bribe the referee' (generated by 5 children), or 'how is the actor dressed' (generated by 14 children, 2 young adults); and (3) the redundant cues, where the same participant asked for the same information many times in different ways (e.g., 'are the two animals heavy' and 'how heavy are the animals'). Overall agreement between raters was high (κ = .93, p < .001). In the few cases where the two raters did not agree, a third rater was consulted.

Almost half of the cues were eliminated through this filtering, leaving 2,000 cues to be analysed. It is important to note that subjective or not assessable cues might be as informative as objective cues, or even more so. However, to assess their predictive value, we would have needed information that was not available or that did not fall into the scope of this experiment. For example, the informativeness of the cue 'beauty' in the actor inference task would have varied between participants. To calculate it, we would have had to ask each participant to assess the beauty of every actor included in the reference class. If the participants' beauty ratings perfectly correlated with the actors' earnings, this would have been an incredibly informative cue. Although it was necessary for our purposes to exclude subjective and not-assessable cues, the fact that many of the generated cues could not be included in our analysis limits the generalizability of our conclusions to the objective cues generated.

Because sometimes participants did not generate any objective cue for a given inference task, we used a mixed-models analysis that allowed all the available data to be considered. A mixed-models analysis with inference task as repeated measure and age group and inference task as fixed effects showed a main effect of age group, $F(1, 89)$ = 7.9, p = .006: Children generated more cues per trial than young adults (M_{children} = 2.82, SD = 1.91; $M_{\text{young\_adults}}$ = 2.44, SD = 1.52). We also found a main effect of the inference task, $F(11, 60) = 42.2$, $p < .001$: Participants generated more cues for some inferences (e.g., which of two houses is more expensive, $M = 5.52$, $SD = 1.84$) than for others (e.g., which of two animals is faster, $M = 1.24$, $SD = 0.91$). The number of cues generated by the participants in the different inference tasks is shown in Table S3.

Type of cues

As expected, we found that overall 54% of the cues generated by children were perceptual, as compared to only 40% of the cues generated by young adults. Children generated in every inference task a higher proportion of perceptual cues than young adults (Table S4), except for the city-temperature task, where children and young adults generated the same proportion of perceptual cues.

Informativeness of the cues

We ran a mixed-models analysis with inference task as repeated measure and age group and inference task as fixed effects. We found that the overall informativeness of the cues generated by the two age groups did not differ ($M_{children} = 0.65$, $SD = 0.09$; $M_{young\_adults} = 0.65$, $SD = 0.09$). We found a main effect of inference task on the informativeness of the cues, $F(11, 31) = 263.70$, $p < .001$: Participants generated cues with higher success for some inferences (e.g., the car-speed task, $M = 0.76$, $SD = 0.08$) than for others (e.g., the actor-earn task; $M = 0.54$, $SD = 0.02$). We also found an interaction effect between age group and inference task, $F(11, 31) = 9.62$, $p = .03$: For some inferences (e.g., the city-population task), children generated cues with higher success than those of young adults ($M_{children} = 0.75$, $SD = 0.08$; $M_{young\_adults} = 0.64$, $SD = 0.08$), whereas in others (e.g., the car-speed task), young adults generated cues with higher success ($M_{children} = 0.72$, $SD = 0.05$; $M_{young\_adults} = 0.8$, $SD = 0.07$). The means related to the informativeness of the cues generated in each inference task by age group are shown in Table S5.

Summary and discussion of Study 1

The results of Study 1 support our hypotheses: Children generated a higher proportion of perceptual cues than young adults, for all inference tasks. We also found no overall difference in the informativeness of the cues generated by children and young adults.

However, surprisingly, the children in Study 1 generated more cues than young adults, for all the inference tasks we tested, even after filtering out the many subjective and not-assessable cues children generated. How is this possible, considering that children have less experience and general knowledge than young adults? To answer this question, it might be useful to break the generation task down to three sequential filtering processes: Availability, memory, and relevance. First, in terms of availability, participants know only a subset of all existing cues, the ones they have had directly or indirectly experienced as predictors in the given task. Second, because of memory or circumstantial constraints (i.e., time pressure, distraction, etc.), participants might be able to recall only a subset of the available cues. Third, among the recalled cues, participants might decide that some cues are not relevant for the task at hand or are not important enough. Only the cues left after this three-step filtering process would eventually be generated.

One possibility is that children generated more cues than young adults because, although they have fewer cues *available* because they have less experience, they are better at *recalling* cues. Another possibility is that children generated more cues than young adults because they did not try too hard to separate the relevant and useful cues from the others. Indeed, children might have simply interpreted the inference tasks in Study 1 as free association problems, of the kind 'tell me any feature you can recall related to this type of object' (e.g., to cars), whereas young adults had filtered out those cues they had discounted (sometimes wrongly) as irrelevant or uninformative for the presented inference task. Study 2 was designed to test these alternative interpretations.

STUDY 2

Study 2 was composed of two parts. The first part implemented a cue-generation paradigm identical to that of Study 1 and explored the contents of children's and young adults' cueboxes for two of the inference problems presented in the previous study. We expected to replicate the results of Study 1 in terms of number, informativeness, and type of cues generated by children and young adults. We designed the second part of Study 2 to disentangle alternative interpretations of why children might generate more cues than young adults, by asking participants why they did not generate a particular cue.

Materials and methods

Participants

Participants in Study 2 were 20 children in the fourth grade (9 female, $M_{age} = 9.10$ years, $SD = 0.31$) and 20 young adults (11 female, $M_{age} = 17.95$ years, $SD = 1.10$) from two schools in Livorno, Italy. The students were all Italian and belonged to various social classes.

Design

The experimental session consisted of a paper-and-pencil questionnaire, collectively administrated in class, divided into three blocks. The first block included two questions, presented in random order on separate sheets, describing two of the problems used in Study 1 (i.e., the city-population and car-price tasks). Participants had 10 min (5 min per task) to generate all the cues they could think of that could help them make each of the two inferences. Participants were repeatedly prompted to generate as many cues as they could.

The second block presented participants with the complete list of cues generated by participants in Study 1 for the city-population and the car-price tasks. The cues were presented in random order, clustered by task. For each cue, participants were asked whether they themselves had generated that cue in the previous block. If not, participants had to select one of the following reasons for not having generated it: (1) I do not know what it means or what it refers to; (2) I did not recall it; (3) I do not think this is relevant or important for the task at hand; or (4) I don't know.

The third block included only one question, testing participants' interpretation of the instructions given in the first block: 'In the previous generation task, did you have to list everything you knew about cars or cities?' Participants could answer yes, no, or I don't know. As in Study 1, participants were told that all the students completing the tasks 'to the best of their ability' would be rewarded with a prize – A box of coloured pencils for the children and a USB stick for the young adults.

Results

Number of cues

In total, participants in Study 2 generated 567 cues. As in Study 1, two adults, blind to the experimental hypotheses and to the tasks, excluded (1) the subjective cues, (2) the cues whose values related to our reference class were not assessable, and (3) the redundant cues. Overall agreement between coders was high ($\kappa = .96$, $p < .001$). In the few cases where the two raters did not agree, a third rater was consulted. This filtering left 374 cues to be analysed.

A univariate analysis of variance (ANOVA) with inference task (cars and cities) as repeated measure and age group as independent variable showed a main effect of age group, $F(1, 38) = 11.50$, $p = .002$, $\eta^2 = .23$: Children generated more cues per trial than young adults ($M_{children} = 5.78$, $SD = 2.93$; $M_{young\_adults} = 3.58$, $SD = 2.26$). We also found a main effect of the inference task, $F(1, 38) = 49.64$, $p < .001$, $\eta^2 = .57$: Participants generated more cues in the cities task ($M_{cities} = 5.85$, $SD = 3.18$) than in the cars task ($M_{cars} = 3.50$, $SD = 1.80$).

Type of cues

As in Study 1, children generated a higher proportion of perceptual cues ($M_{cities} = 75\%$, $SD = 9\%$; $M_{cars} = 59\%$, $SD = 19\%$) than young adults ($M_{cities} = 62\%$, $SD = 33\%$; $M_{cars} = 29\%$, $SD = 28\%$), $t(38) = 3.75$, $p = .001$. The proportion of perceptual cues was higher in the city-population task than in the car-price task, $t(39) = 4.59$, $p < .001$.

Informativeness of the cues

A univariate ANOVA with inference task (cars and cities) as repeated measure and age group as independent variable showed that the overall informativeness of the cues generated by the two age groups did not significantly differ ($M_{children} = 0.73$, $SD = 0.05$; $M_{young\_adults} = 0.72$, $SD = 0.06$, $p = .577$). We found a main effect of inference task on the informativeness of the cues, $F(11, 38) = 14.87$, $p < .001$, $\eta^2 = .30$: Participants generated cues with higher success in the city-population task than in the car-price task ($M_{cities} = 0.75$, $SD = 0.05$; $M_{cars} = 0.70$, $SD = 0.05$).

Reasons why some cues were not generated

Compared to young adults, children rated a higher percentage of the given cues that they did not generate themselves as *unknown* ($M_{children} = 12\%$, $SD = 16\%$; $M_{young\_adults} = 4\%$, $SD = 9\%$), $t(33) = 3.13$, $p = .004$ (Figure 1). Despite the age trend, a *t*-test analysis revealed no difference between the proportions of the given cues that children ($M_{children} = 53\%$, $SD = 22\%$) and young adults ($M_{young\_adults} = 43\%$, $SD = 19\%$) reported they could not recall ($p = .110$). However, young adults rated a higher percentage of the given cues not generated by themselves as not relevant for the task at hand ($M_{young\_adults} = 53\%$, $SD = 19\%$), as compared to children ($M_{children} = 31\%$, $SD = 14\%$), $t(33) = 3.48$, $p = .001$.

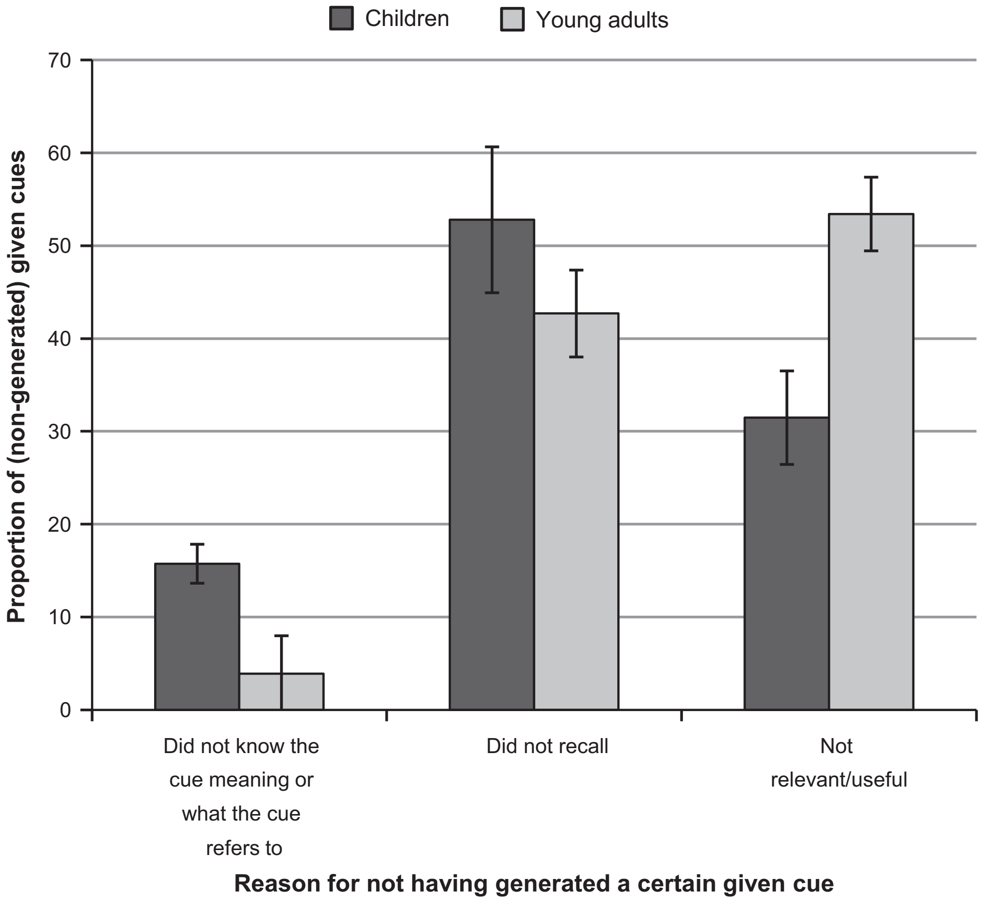

Figure 1. Average proportion of the given cues in Study 2 that participants, according to their self-reports, did not generate because they did not know them, they could not recall them, or they considered them as not relevant for the task at hand. Results are displayed by age group. Bars indicate standard errors.

Interpretation of the task

More than half of the children (11 of 20) believed that the instructions in the first task were to list *everything* they knew about cars/cities. However, none of the young adults believed those were the instructions.

Summary and discussion of Study 2

The results of Study 2 replicated the three key findings of Study 1: Children generated more cues than young adults; children generated a higher proportion of perceptual cues than young adults; and the cues generated by children and young adults, overall, did not differ in terms of informativeness.

We designed Study 2 to further investigate the unexpected result of Study 1 that children generated more cues than young adults, allowing us to disentangle several alternative interpretations. The results seem to suggest that children have fewer cues *available* than young adults, that is they know fewer cues, as hypothesized. Indeed, children more often than young adults reported that they had not generated a certain given cue because they did not know it. There seems to have been no difference in participants' self-reported ability to recall available cues. However, young adults reported more often than children that they had not generated a certain given cue, although they knew it, because they did not consider it relevant for the task at hand. This analysis suggests that young adults generated fewer cues than children because, although they had more cues available, they deemed some of the cues they had available as not relevant or important enough to be generated. Participants' general interpretation of the task's instructions might have contributed to the age differences in how the relevance filter was implemented: More children, as compared to young adults, reported having interpreted the task as a free-association task, of the kind 'tell me everything you know that is related to this type of object' (e.g., to cars). Of course, these conclusions are based on children's and young adults' self-reports and should be explored in future studies with other methodologies.

Knowing what is in a person's cuebox does not reveal much about which cues are considered the most informative. In Studies 3 and 4, we investigated which cue children and young adults identify as the most informative one when selecting cues from their cuebox (Study 3) or when selecting between two given cues (Study 4). In particular, in both studies, we examined how the type of cue (i.e., perceptual or hidden) influences the process of generation/selection.

STUDY 3

In Studies 1 and 2, children generated cues that were, overall, as informative as the cues generated by young adults. This does not mean that children can *assess* the informativeness of the cues in their cuebox, to select the most informative cue among those they could generate. However, because the children generated the cues themselves, we assumed that they were familiar with them and maybe had direct experience with those cues being informative in the presented inference tasks. Therefore, an intriguing possibility is that the cues children select from their cuebox and identify as the most informative ones are, on average, as informative as the cues selected by young adults.

Furthermore, in the first two studies, children generated a higher proportion of perceptual cues compared to young adults. On the basis of previous literature showing that young children tend to focus spontaneously on perceptual over hidden properties in causal or categorization tasks (Gelman & Davidson, 2013; Gentner, 2010; Keil & Batterman, 1984), we hypothesized that a greater proportion of children, as compared to young adults, would identify, among the cues in their cuebox, and generate a perceptual cue as the most informative. To test this hypothesis, we asked participants to generate what they deemed the one most informative cue for the inference problems presented in Study 1.

Materials and methods

Participants

Participants in Study 3 were 50 children in the fourth and fifth grade (26 female, M_{age} = 10.11 years, SD = 0.27) and 33 young adults (15 female, M_{age} = 17.62 years, SD = 0.86) from two schools in Livorno, Italy. The students were all Italian and belonged to various social classes.

Design

In Study 3, participants were presented with a paper-and-pencil questionnaire collectively administrated in class. The questionnaire consisted of the 12 inference tasks used in Study 1 (Table 1), presented to each participant in a different random order. Children and young adults were asked to generate only the cue they considered the most helpful in making the inference. For example, participants were told: 'If you could ask only one question to find out which of two cities has more inhabitants, what would you like to know about them?' They were given 5 min for each inference task. We told the participants that the child and young adult generating the overall most successful cues, defined as the cues that would be most predictive of the correct inference, would be rewarded with a €25 Amazon gift card.

Results

Type of cues

Children generated a higher proportion of perceptual cues (based on Study 1's classification of perceptual and hidden cues) than young adults (children: 47%; young adults: 19%) for all inference tasks, $t(81) = 6.01$, $p < .001$ (see Table S6).

Informativeness of the cues

We ran a mixed-models analysis with inference task as repeated measure and age group and inference task as fixed effects. We found no main effect of age group but did find an effect of inference task, $F(11, 92) = 278.83$, $p < .001$. Participants' generated cues were more successful for some inferences (e.g., city-temperature task, $M = 0.85$, $SD = 0.06$) than for others (e.g., actor-earn task, $M = 0.51$, $SD = 0.07$). Table S7 shows the average success of the cues generated by participants in the two age groups, for each inference task.

Summary and discussion of Study 3

In Study 3, we asked children and young adults to generate which cue they deemed the most informative one for the inference problems presented in Study 1. Confirming our hypothesis, and consistent with the results of Studies 1 and 2, the cues generated as most informative by children and young adults did not differ in informativeness, in any of the considered inference tasks. Children might be as good as adults at selecting informative cues from their cuebox because, being familiar with the cues in their cuebox, they are accurate in assessing their informativeness. We also found that, as expected, a higher proportion of children generated a perceptual cue as the most informative, as compared to young adults, who more often generated hidden cues. In Study 4, we investigated how efficient children and young adults are when selecting the most informative between given cues.

STUDY 4

In Study 4, we asked children to select the most informative of two given cues for two inference tasks. We assumed that young adults would be more experienced and familiar than children with the given cues. Thus, we hypothesized that in Study 4 young adults would be better than children at selecting the most informative of the two given cues, independent of the cues' type. In contrast, we expected children to select the most informative cue only when both the given cues were perceptual and therefore more likely to be familiar.

Materials and methods

Participants

Participants in Study 4 were 37 children in the fourth and fifth grade (20 female, M_{age} = 9.76 years, SD = 0.60) and 18 young adults (8 female, M_{age} = 17.22 years, SD = 0.43) from four schools in Livorno, Italy. The students were all Italian and belonged to various social classes.

Design

Study 4 consisted of 12 trials, presented to each participant in a different random order on a computer screen. In each trial, participants had to select from two given cues the one they wanted to know about before making an inference.

There were two possible inferences: Which of two cell phones, among those currently sold by the store Media Market, was more expensive, and which of two cars, among those currently produced by Fiat, was more expensive. The objects were displayed at the top of the screen and given generic labels (e.g., Car 1 and Car 2). The cues were labelled (e.g., internal memory of the mobile phone) and presented in the middle of the screen, in random order. Participants were told they could click on only one of the cues before making the inference. After participants selected a cue, they would see the value of both objects for that cue (e.g., Mobile Phone 1: 16 GB; Mobile Phone 2: 1 GB) and had to make the inference, selecting the object they thought was more expensive.

Each inference task was presented to the participants in six trials. In each trial, participants received one of six possible combinations of two cues taken from a set of four cues: A perceptual/high-success cue, a hidden/high-success cue, a perceptual/low-success cue, and a hidden/low-success cue. Table 2 shows a list of the cues used for Study 4. We chose these two inference tasks, from the 12 used in the other two studies, because they satisfied two crucial conditions: (1) we found among the cues generated for these inferences in Study 1 examples of all four cue categories mentioned above, and (2) we could find two pairs of high-success and low-success cues with similar success rates (Table 2).

The given object pairs were the same across participants and were chosen so that the high-success cue would always point to the correct inference, whereas the low-success

Table 2. Cues used in Study 4 and their success

	High success		Low success	
Cue type	Cue	Success	Cue	Success
Cell phone price				
Hidden	Memory	.89	Battery life	.52
Perceptual	Thickness	.82	Camera	.55
Car price				
Hidden	Capacity	.76	Fuel consumption	.52
Perceptual	Length	.77	Doors	.63

cue would always point to the wrong inference. Children were not given feedback until the end of the six trials. There was no time limit. Participants were told that the children and young adults with the highest number of accurate inferences would be rewarded with a €25 Amazon gift card.

Results

Participants' inferences were always consistent with the cue values observed (e.g., the mobile phone with more memory costs more). This means that all participants were able to correctly interpret the direction of the cues (e.g., more memory means higher price, but less thickness means higher price).

Because we found no difference between the two inference tasks, we present the results for the two tasks together. In trials where participants were given two equally successful cues, both children and young adults selected the hidden cue more often (M = 76%, SD = 23%). In trials where participants were given two cues of the same type, both children and young adults selected the high-success cue more often (M = 61%, SD = 23%). When both cues were perceptual, children selected the high-success cue about as often as young adults ($M_{children}$ = 58%, SD = 36%; M_{young_adults} = 42%, SD = 31%), p = .105. However, when both cues were hidden, young adults selected the high-success cue more often than children ($M_{children}$ = 62%, SD = 27%; M_{young_adults} = 86%, SD = 23%), $t(53) = 3.20$, p = .002. In trials where participants were given a perceptual/low-success cue and a hidden/high-success cue, participants were able to select the high-success cue more often ($M_{children}$ = 78%, SD = 35%; M_{young_adults} = 89%, SD = 21%), with no differences between age groups, p = .467. In trials where participants were given a perceptual/high-success cue and a hidden/low-success cue, participants, overall, selected the hidden/low-success cue more often (M = 62%, SD = 47%). Children selected the hidden/low-success cue in more trials ($M_{children}$ = 73%, SD = 42%) than young adults (M_{young_adults} = 52%, SD = 47%), $t(53) = 2.49$, p = .017.

Summary and discussion of Study 4

In Study 4, we found that young adults were overall better than children at selecting the more informative of the two given cues, independent on the cues' type. We found that when participants were given a perceptual and a hidden cue, both being high- or low-success cues, they overall more often selected the hidden one. We also found that in trials where the two cues presented were both perceptual or both hidden, the participants could not always identify the most informative one.

Crucially, in trials where participants had to select between less successful hidden cues and more successful perceptual cues, children selected the perceptual/high-success cue in only a few trials, and also, young adults selected it in only about half the trials. These results suggest that when required to choose between given cues, both children and young adults had a general tendency to consider hidden cues as more informative than perceptual cues, even in trials when they were not.

GENERAL DISCUSSION

In this series of studies, we opened and compared children's and young adults' cueboxes, examining the number, type, and quality of cues they could generate when making a range of inferences from memory (Studies 1 and 2). Moreover, we tested whether children and young adults could select the most informative cue and studied the relationship between the type and the informativeness of the cues in a cue-generation (Study 3) and cue-selection (Study 4) paradigm.

Our results show that, surprisingly, there is no overall difference in the informativeness of the cues generated by children and young adults, for any of the considered inference tasks. Moreover, the results from Studies 1, 2, and 3 support our hypothesis: Children generated a higher proportion of perceptual cues than young adults, for all inference tasks. These findings fit with the definition of children as 'perceptually oriented' (Flavell, 1985; John & Sujan, 1990; Wartella, Daniel, Scott, Jacob, & Allison, 1979). Younger children have overall less knowledge of and experience with objects and their hidden features and tend to spontaneously focus on perceptual over hidden properties (Gelman & Davidson, 2013; Gentner, 2010; Keil & Batterman, 1984). As children grow up, the process of updating their knowledge through experience also leads to an update of their cueboxes. A continuous enrichment (and enlargement) of the cuebox is accompanied by a constant, progressive refinement (and selection) of the cues included. Indeed, the results of Study 2 suggest a development of the cuebox across the lifespan: New cues are added to the cuebox as more cues are learned and become available, and some 'old', perceptual cues, although informative, are dropped and *replaced* with hidden cues, which are apparently assumed to be generally more informative than perceptual cues, both by children and by young adults (see Study 4).

Why? Because hidden cues are learned through direct experience or interaction with peers or more knowledgeable others (i.e., parents, teachers, etc.), they appear to be more appropriate and more sophisticated than the more obvious perceptual cues, and this might lead people to assume they are also more informative, even when they are not. This could explain why, on average, the cues generated by children and young adults did not differ in terms of informativeness, not even in Study 3, when participants were prompted to generate the most informative cue.

Our results indicate that number, informativeness, and type of generated cues seem to be very robust across different studies and domains. In particular, despite the difference in absolute number and informativeness of the generated cues across domains, with participants generating more cues and more informative ones for some inferences than for others,[2] we found that the qualitative pattern of our results hold across the 12 inference tasks studied in Studies 1 and 3, with no exceptions. Future research might assess and manipulate children's familiarity with different inference tasks to examine more closely the interplay between experience and generated cues.

In this paper, we decided to operationalize the definition of perceptual and hidden cues empirically, by asking a sample of children and adults to categorize the cues generated by participants. Future research may look for an *a priori* definition of the conceptual boundaries of perceptual and hidden cues. These category boundaries might be fluid across development, especially when considering younger age groups (e.g., toddlers and preschoolers). For example, toddlers might consider the cue 'gears' as hidden, because it is more difficult for them to observe its value. Such shift might influence the cuebox updating process across the lifespan.

Finally, although it was necessary for our purposes to exclude subjective and not-assessable cues, the fact that many of the generated cues could not be included in our

[2] *Note that participants might have generated cues that are more informative in some inference tasks because better cues are available for those domains.*

analysis of Study 1 limits the generalizability of our conclusions to the objective cues generated.

Our findings contribute to the research investigating the advantages of self-directed learning (Gureckis & Markant, 2012), which it is widely thought to improve learning, particularly in educational contexts (Klahr & Nigam, 2004; Mayer, 2004). The present research has laid the groundwork for studying self-directed cue-based decision-making in more natural settings, where people not only have to search for information but also have to generate from memory the information they want to search for. Indeed, there are many *shades* of self-directed learning, some more 'active' than others. Complementing the findings that self-directed learning can be more beneficial than more passive forms of learning, our results show that 'active' forms of self-directed learning, namely cue-generation paradigms, might also be more beneficial than more 'passive' forms of self-directed learning (i.e., cue selection), especially for children.

Conclusions

This research shows that because perceptual cues can be as informative as hidden cues, being 'perceptually oriented' does not disadvantage children. However, beneficial reliance on perceptual cues is only possible in cue-generation tasks, for two reasons: First, because children are familiar with the cues they themselves generate and therefore can be accurate in assessing their informativeness; second, because children are not confused by the presence of hidden cues they do not know, which both children and young adults tend to assume are more informative, even when they are not.

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Supporting Information

The following supporting information may be found in the online edition of the article:

Table S1. Cues, percentage of participants rating the cue as perceptual, resulting cue type, and success of cues generated in Study 1 by young adults and children (proportions within age groups).

Table S2. Information sources for completing the databases used to calculate informativeness in Studies 1, 2, and 3.

Table S3. Average number (and standard deviations) of cues generated by the participants in Study 1.

Table S4. Average proportion (%) of cues generated in Study 1 that were perceptual cues.

Table S5. Informativeness, in terms of success, and standard deviations of the cues generated by the participants in Study 1.

Table S6. Average proportion (%) of all cues generated in Study 3 that were perceptual cues.

Table S7. Informativeness, in terms of success, and standard deviations of the cues generated by the participants in Study 3.