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Food as a borderline domain of knowledge: The development of domain-specific inductive reasoning strategies in young children

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ABSTRACT

This study investigated how young children's inductive reasoning abilities pertain to the food domain in comparison with the natural kind and artifact domains. Two research hypotheses were tested: H1) Younger children (4–5 years) exhibit less differentiated inductive reasoning strategies between natural kind, food, and artifact domains of knowledge than older children (6–7 years) and H2) induction strategies are impacted by the degree of processing of the food (i.e. unprocessed, sliced, and pureed). Younger ($n = 44$, 4–5 years) and older children ($n = 52$, 6–7 years) were tested as well as a control group of adults ($n = 48$). Results confirmed H1) and only partial results obtained from older children (6–7 years) spoke in favor of H2). We conclude that these pieces of evidence cast a reasonable doubt on the shared assumption that foods are natural kind entities, and consequently open new research avenues for evidence-based food education programs.

1. Introduction

Categories promote inductive inferences differently based on the domain of knowledge to which they correspond. According to some theorists, categories emerge from domain specific systems of knowledge (Caramazza & Shelton, 1998; Carey, 1985; Chomsky, 1980; Hirschfield & Gelman, 1994; Kelemen & Bloom, 1994). A domain specific system of knowledge is a structure of information organized around a set of rules or constraints on the underlying cognitive mechanisms, such as induction, which applies to a particular set of entities (e.g. animals). One of the most documented and debated domain difference is between artifacts versus natural kind categories. Indeed, there is a relative consensus that the categorization of natural kinds (i.e. naturally occurring entities, such as animals and plants) triggers inferences of the category's essence, namely: substance, insides or internal biological properties (Ahn et al., 2001; Dar-Nimrod & Heine, 2011; Estes, 2003; Gelman, 2003; Newman & Knobe, 2019; Xu & Rhemtulla, 2005). By contrast, categorization of artifacts (i.e. human made entities, such as tools and toys) triggers inferences of the object's intended function (Casler & Kelemen, 2007; Kimura, Hunley, & Namy, 2018; Matan & Carey, 2001) and the object's history (Gutheil, Bloom, Valderrama, & Freedman, 2004). Furthermore, category *structure* varies according to the domain of knowledge at hand. Indeed, both adults and

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children view natural kind categories (e.g., animals in the majority of studies) as having discrete, sharp and objective boundaries, whereas they tend to consider artifact categories as more flexible and subjective (Rhodes & Gelman, 2009a). Additionally, category membership is absolute for natural kinds, but may be graded for artifacts (1998, 2004, Diesendruck & Gelman, 1999; Estes, 2003; Kalish, 1995; Malt, 1990). Children apply these structural differences to natural kinds and artifacts by the age of 5-years (Rhodes & Gelman, 2009a, 2009b).

In many cases, though, the distinction between natural kind and artifact categories is far from being clear-cut, and borderline cases such as cultivated fruits (Gelman, 1988) have been disregarded and remain under-researched thus far. Indeed, food items originate from naturally occurring entities, but often have a history of human intervention as well (e.g., being cultivated, being processed). Furthermore, from an early age, children understand that natural foods grow naturally outside, while processed foods are made by humans in factories and are not naturally occurring (Girgis & Nguyen, 2020). However, it remains an open empirical question if children's inductive strategies differ between food types and non-food natural kinds and artifacts.

Neuropsychological evidence obtained from adult patients found distinctions in semantic memory subsystems, which support that food categories may be considered as a borderline case. According to the sensory-functional hypothesis (Warrington & Shallice, 1984), semantic memory is organized in at least two distinct subsystems that can be specifically impaired. The first one represents the sensory properties of objects and the second one represents the functional properties of objects. According to the proponents of this theory, recognition of living things would mainly rely upon the first system and the recognition of non-living things would critically depend on the second system (Borgo & Shallice, 2001, 2003). From a theoretical perspective, the food domain is of particular interest since it cuts across the living/non-living distinction (e.g. oysters versus salt) or the distinction between natural and manufactured objects (Capitani, Laiacona, Mahon, & Caramazza, 2003, p. 225; Rumiati and Foroni, 2016).

Recent pieces of empirical evidence, generated by neuropsychological tests and conducted on patients suffering from either Alzheimer dementia or Primary Progressive Aphasia have found in some cases, category-specific deficits that affect recognition of natural food, manufactured food, and living things, but spare recognition of non-living things (Vignando et al., 2018). However, in other patients, the ability to recognize natural food dissociates from the ability to recognize processed food (Rumiati and Foroni, 2016 for a review). These conflicting pieces of evidence led the authors of these seminal studies to suspect that the food domain is not homogeneous and further investigation on the influence of food variables on categorization is needed before determining how food knowledge is organized in the brain. The degree of food processing (or the level of food transformation) is one such variable that has a major influence on the inferences made about foods (Rumiati and Foroni, 2016). For instance, adults make inferences more readily for biological properties when confronted with unprocessed food (e.g., an apple), compared to making inferences about function when confronted with processed food (e.g., a slice of apple pie). Indeed, Pergola, Foroni, Mengotti, Argiris, and Rumiati (2017) observed that when a photograph of an unprocessed food was introduced and followed by a sensory sentence (e.g., it tastes salty), participants were better at detecting incongruence (e.g., apples taste salty) than when the same photograph was followed by a functional sentence (e.g., apples are suitable for a wedding meal). Opposite results were obtained for photographs of processed food.

Moreover, it has been shown that young children rely on perceptual features to extract function information in order to categorize objects (Kemler Nelson, Russell, Duke, & Jones, 2000; Kemler Nelson, Herron, & Morris, 2002; Trauble & Pauen, 2007). Regarding food, the level of food processing may convey function information as well. It could be that the level of processing that is done to a food can change directly or indirectly its edibility. The direct way would correspond to the notion of *observed functional affordance* (e.g., this chopped vegetable can be eaten more easily). The indirect way would correspond to the possibility that children infer the *agent's intention* from a perceived level of food processing (e.g., this vegetable has been chopped *by a chef who wanted* to make it easier to eat) (Diesendruck, Markson, & Bloom, 2003; Jaswal, 2006).

These studies suggest that the food domain could be a borderline case with respect to the fundamental distinction between naturally occurring and human made entities. However, despite Susan Gelman's suggestion that "cultivated fruits" (Gelman, 1988, p. 69) could constitute a borderline case, almost no developmental evidence has been obtained so far on the development of induction strategies based on food categories, in comparison with natural kind and artifact categories.

1.1. The current study

The present study builds on Gelman (1988)'s first investigation using an induction task based on natural kind and artifact categories. Interestingly, Gelman (1988)'s primary research question was not '*When do children begin to draw inductive inferences from categories?*', but rather '*When do children begin to exhibit specific category-based strategies of inductive reasoning, and how do these patterns change with development?*' Here, by "specific category-based strategies", we mean induction response patterns limited or constrained by the type of categories, which for this study is natural and processed foods, non-food natural kinds and artifacts. For instance, object *naturalness* is introduced by Gelman (1988) as one of the main category variables constraining induction and, consequently, as a fundamental way of preventing us from unwarranted inductive inferences (on the philosophical problem of induction see Goodman, 1955; Hume, 1739, 1748). Object naturalness is a domain-specific factor, which constrains inductive reasoning by facilitating the generalization of essential properties within the domain of natural kinds but not artifacts. To determine when and how exactly young children limit their induction on the basis of object naturalness, preschoolers and second graders were told a "novel" property (e.g. "has pectin inside") about a particular object (represented by a picture, such as a red apple) and were asked to decide whether this fact also applied to other objects, including members and non-members of the initial picture category (e.g. another red apple, a yellow apple, a banana and a stereo). All the training and test stimuli were either non-food natural kinds, human-made artifacts, or food items, mainly fruits and vegetables, which were considered as naturally occurring. Different types of properties were used, including essential and functional properties, respectively generalizable to natural kinds and to artifacts. Gelman (1988) observed that object naturalness was a significant predictor of children's inductions (number of inferences drawn) only for second graders and only at the basic level, which is the default level of categorization. For example, from a red apple to a yellow apple, by contrast with more abstract superordinate categories (e.g. from a red apple to a banana) or more specific subordinate categories (e.g. from one red apple to another red apple).

The present study aims to extend Gelman (1988) by investigating 4- to 7-year-olds' category-based inductive reasoning strategies in the food domain compared with non-food natural kinds and artifacts. This age range is consistent with those used in Gelman (1988) and it is the age at which young children tend to exhibit food rejection (i.e. food neophobia and picky/fussy eating, Lafraire, Rioux, Giboreau, & Picard, 2016 for a review). Food rejection represents a significant source of inter-individual variability with regard to children's induction performance in the food domain (Rioux, Lafraire, & Picard, 2017; Rioux, Leglaye, & Lafraire, 2018).

In the present study, food processing (i.e. being cut versus pureed) was manipulated as well as the type of property (i.e. essential versus functional) that the children were asked to generalize within or across the three putative domains of knowledge (non-food natural kind, artifact, food). Since processing a food item often impacts recognition and familiarity that may negatively impact induction performance, all the exemplars belonging to the three domains of knowledge were unfamiliar. Similarly, novel properties were used to reduce the inter-individual variability resulting from background knowledge about food properties that might fluctuate among the children.

Two research hypotheses were specifically tested:

H1. Younger children (4−5 years) will exhibit less differentiated inductive reasoning strategies between non-food natural kind, food, and artifact domains of knowledge as compared to older children (6−7 years).

The key test for testing domain differentiation, along with the development of inductive reasoning abilities in young children, is the following. We will interpret a higher probability to generalize the property within the same domain (intra-domain facilitation) and a lower probability to generalize the property, if the target and the presented test stimuli belong to different domains (artifact and natural kind), as evidence that inductive reasoning is sensitive to the domain of knowledge.

H2. Inductive reasoning patterns are impacted by the degrees of food processing (i.e. unprocessed, sliced, and pureed).

More specifically, we expected that degrees of food processing convey function information about food stimuli, which in turn could increase the probability of ascribing a functional (e.g. "can zulinize the heart") versus an essential property ("made of zuline") to processed foods. Furthermore, we hypothesize that the more processed a food stimulus, the more distant it is from the natural kind domain. Consequently, when it comes to generalizing a property from a non-food natural kind exemplar to food stimuli, we expect to observe fewer generalizations to processed food stimuli than to unprocessed ones.

2. Methods

2.1. Participants

The participants were ninety-six children: forty-four 4- to 5-year-olds (M_{age} = 4;10; *SD* = 5.45 months, *range* = 48–71 months, 27 females), and fifty-two 6- and 7-year-olds M_{age} = 7; 10; *SD* = 3.90, months, *range* = 74–88 months, 26 females). We refer to the 4- and 5-year-olds as the younger group and the 6- and 7-year-olds as the older group. This sample size was chosen to match previous sample sizes of studies with similar designs (e.g., Gelman, 1988; Gelman & Markman, 1987; Rioux et al., 2018). Fourteen additional 3-year-old children were tested but excluded due to their non-comprehension of the task (i.e. they were either unable to answer or they persisted in one type of response regardless of the condition). The children were all pupils at preschools located within middle-class communities in XXX and XXX (XXX) and were predominately Caucasians. Ethical approval from a local Ethics Committee (XXX) was obtained for a similar experiment and population (see XXX) and parents gave written consent for their child's participation. The procedure was in accordance with the Declaration of Helsinki and followed institutional ethics board guidelines for research on humans.

Prior to the study, parents filled out the Children Food Rejection Scale (CFRS, Rioux, Lafraire, & Picard, 2017). The CFRS includes two subscales corresponding to two dimensions of food rejection: food neophobia (6 items) and pickiness (5 items). Caregivers were asked to what extent they agree with statements regarding their child's neophobia (e.g. "*My child rejects a novel food before even tasting it*") and pickiness ("*My child rejects certain foods after tasting them*"). Caregivers rated each item on a 5-point Likert-like scale (1 = *Strongly disagree*, 2 = *Disagree*, 3 = *Neither agree nor disagree*, 4 = *Agree*, 5 = *Strongly agree*). Each answer was numerically coded with high scores indicating higher food neophobia and pickiness (scores could range from 6 to 30 for neophobia and 5–25 for pickiness; food neophobia scores: *M* = 15.70, *SD* = 4.94; food pickiness scores: *M* = 16.65, *SD* = 4.26). This questionnaire was administered because food rejection disposition seems to negatively influence inductive reasoning performance in preschoolers (Rioux et al., 2017a, 2018).

A control group of young adults (*n* = 48) also participated and were used as a comparison point for children's developing inductive inference abilities. Indeed, since the children were asked to generalize novel properties to unfamiliar items, there was no correct answer to assess the development of children's induction patterns. Therefore, we had to compare children's inductions with adults' to test our developmental hypothesis. The testing procedure of the induction task was the same for children and adults.

To better interpret observed effects of food processing[1] on children's inductions, a follow-up online test was conducted with Qualtrics© on 65 young adults who were recruited online via a university email list (M_{age} = 26 years, *SD* =11 years, 53 female). See

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[1] The authors would like to thank an anonymous reviewer for having stressed the importance of such additional data collection.

Section 2.3.1 below for the rationale and the details of the procedure).

2.2. Materials

The materials consisted of 54 color photographs of unprocessed food (unprocessed fruits and vegetables, labeled as F0, $n = 12$, see Fig. 1a), cut food (cut fruits and vegetables, labeled as F1, $n = 9$, see Fig. 1b), pureed food (pureed fruits and vegetables, labeled as F2, $n = 9$, see Fig. 1c), natural kinds (flowers, labeled as NK, $n = 12$, see Fig. 1d) and artifacts (parts of tools without any salient functional properties, labeled as A, $n = 12$, see Fig. 1e) that varied in shapes and colors. All stimuli were chosen to be unfamiliar to participants. Pictures of foods belonged to the same food categories, namely fruits and vegetables. This was done in order to reduce the differences of energy density between the stimuli. The processed foods (cut and pureed food, e.g., cut cucumber) were not processed versions of the unprocessed food (e.g., star fruit), but rather different foods. Each picture was printed on a laminated card measuring 14.8cm × 21cm.

To generate this picture set, we first selected 62 pictures of *a priori* unfamiliar foods (fruit and vegetables), natural kinds (flowers) and artifacts (tools), from a variety of internet sites and published picture databases (e.g., FoodCast database; Foroni, Pergola, Argiris, & Rumiati, 2013). Subsequently, twelve 4- to 7-year-old children participated in a picture categorization task and a picture identification task. None of these children participated in the actual study. In the picture categorization task, children were told (translated from French): “I will show you extraterrestrial things and it’s up to you to tell me if it is more of a tool, a food or a flower”. The experimenter recorded whether each of the 62 pictures were properly categorized (e.g., for a food picture, when a child said “it is a food”, “it is something that looks like a food” or “it is something that can be eaten”). Secondly, children participated in an identification task where they were asked whether they recognized each picture. The purpose of this identification task was to control for the unfamiliarity of the stimulus. We kept the stimuli pictures that were successfully categorized by more than 70 % of the children, but not being recognizable. The rest of the pictures were removed due to their high rate of incorrect categorization or due to their resemblance to a familiar item (inferred from children’s misidentifications during the pretest).

2.3. Procedure

Children and adults were tested individually for approximately 10 min in a quiet room. They sat at a table, with an experimenter on their side, and were told that they would play a game that consists of sorting objects found on a planet far away.

Prior to each testing session, the experimenter randomly chose two pictures of an unprocessed fruit (F0, see Fig. 1a), to be the *training pictures*. Then, for each *training picture* the experimenter selected five pictures to be *test pictures*: (i) a picture of an unprocessed fruit (F0, see Fig.1a), (ii) a picture of a cut fruit (F1, see Fig. 1b), (iii) a picture of a pureed fruit (F2, see Fig. 1c), (iv) a picture of a flower (NK, see Fig. 1d) and (v) a picture of a tool (A, Fig. 1e). The picture was chosen randomly within each category. One *training picture* and its five *test pictures* constituted a block (see Table 1). Then, the experimenter randomly chose two pictures of a flower (NK, see Fig. 1d), to be *training pictures* as well as five *test pictures* for each flower *training picture*. Finally, the experimenter randomly chose two pictures of a tool (A, see Fig. 1e), to be *training pictures* as well as five *test pictures* for each tool *training picture*. After this selection process, the picture set was divided into six blocks of six pictures (one *training* and five *test pictures,* see Table 1 for a description of the six blocks).

It is important to note that, whilst the structure of blocks was identical for each child, because the pictures were pseudo-randomly selected, the specific pictures in a given block were different from one child to another (i.e., the same picture in Fig. 1a could be a *training picture* in block 1 for one participant and a *test picture* in block 2 for another participant). This selection process was chosen to avoid as much as possible any color or shape similarities between pictures within a block, because color and shape similarities between *training* and *test pictures* have an impact on children’s performance of category-based induction tasks (Badger & Shapiro, 2012; Gelman & Markman, 1987; Sloutsky & Fisher, 2004).

During the testing session, participants were shown the blocks, one after the other. For each block, they learned a novel property about the *training picture* and were asked whether the five *test pictures* also possess the property. To ensure that children did not draw on previous knowledge to make property predictions during the task, we used novel properties similar to Fisher, Matlen, and Godwin (2011) and Rioux et al. (2017a). We tested two types of property: *essential* properties (e.g., “is made of zuline”) and *functional* properties (e.g., “can zulinize your heart”; see Gelman, 1988 for a similar paradigm with familiar properties). See Table 2 for the list of properties used.

For each block, the instructions were as follows (translated from French): “This food [example when the training picture was F0] is made of zuline [example when the property was essential, see block 1 in Table 1]. We then hang the picture on the box that contains things that are made of zuline. Now, I will show you more pictures {without naming the pictures} and I want you to tell me if we should put it in the box of things that are made of zuline. If not, you will have to put it in the other box. Do you think this {pointing to the first *test picture* without naming it} goes in the box of things that are made of zuline or in the other box?” (the same question was then asked for the next four *test pictures*, shown successively).

Since unfamiliar stimuli and novel properties were used, superordinate level labels (i.e., “food”, “flower” and “tool”) were given for the *training pictures only* to facilitate and reduce the ambiguity of the task (Gelman & O’Reilly, 1988). Three blocks were associated with an *essential* property and three blocks were associated with a *functional* property (see Table 1). The order of block presentation was randomized across participants, with the constraints that two consecutive blocks contain different types of training pictures (e.g., F0 and NK) and were associated with a different property type (see Table 1). The property that was used for each block was also counterbalanced across participants.

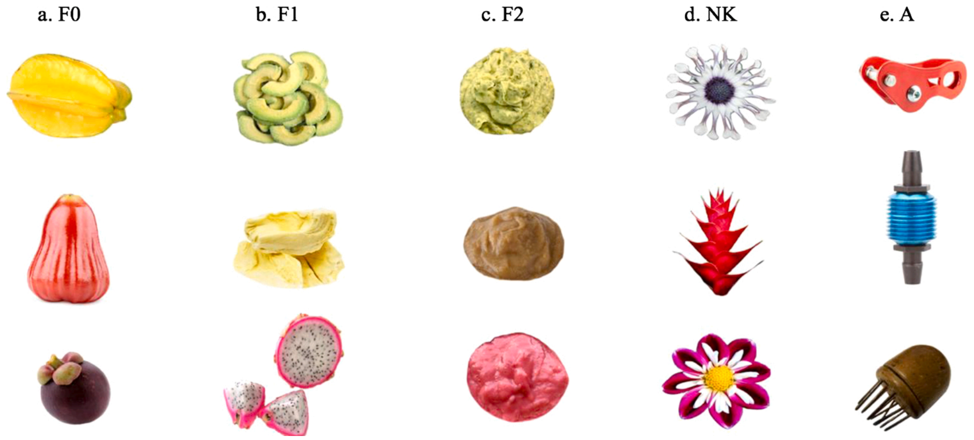


Fig. 1. Examples of stimuli.
Notes. F0: unprocessed food (unprocessed fruit and vegetables); F1: cut food (cut fruit and vegetables); F2: pureed food (pureed fruit and vegetables); NK: natural kind (flower); A: Artifact (tool).

Table 1
Experimental design.

Block #	Training Pictures	Property	Test Pictures
1	Unprocessed food (F0)	Essential (e.g., "this food is made of zuline")	Unprocessed food (F0) Cut food (F1) Pureed food (F2) Flower (NK) Tool (A)
2	Flower (NK)	Functional (e.g., "this flower can kazolize your heart")	Unprocessed food (F0) Cut food (F1) Pureed food (F2) Flower (NK) Tool (A)
3	Tool (A)	Essential (e.g., "this tool is made of Lima")	Unprocessed food (F0) Cut food (F1) Pureed food (F2) Flower (NK) Tool (A)
4	Unprocessed food (F0)	Functional (e.g., "this food can dax your heart")	Unprocessed food (F0) Cut food (F1) Pureed food (F2) Flower (NK) Tool (A)
5	Flower (NK)	Essential (e.g., "this flower is made of pugne")	Unprocessed food (F0) Cut food (F1) Pureed food (F2) Flower (NK) Tool (A)
6	Tool (A)	Functional (e.g., "this tool can tobilize your heart")	Unprocessed food (F0) Cut food (F1) Pureed food (F2) Flower (NK) Tool (A)

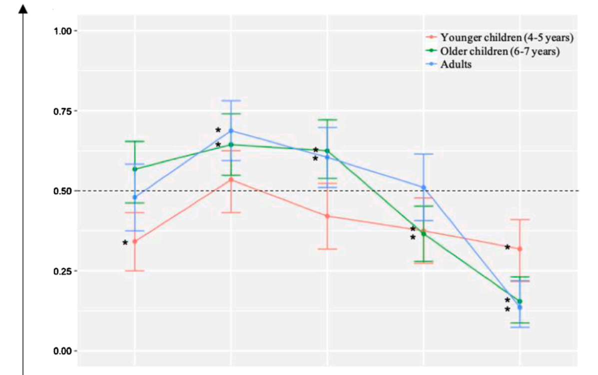
Table 2
List of properties used in the experiment.

Essential property	Functional property
Is made of Zuline	Can zulinize the heart
Is made of Kazole	Can kazolize the heart
Is made of Lima	Can Limanize the heart
Is made of Dax	Can dax the heart
Is made of Pugne	Can Pugnilize the heart
Is made of Tobi	Can Tobilize the heart

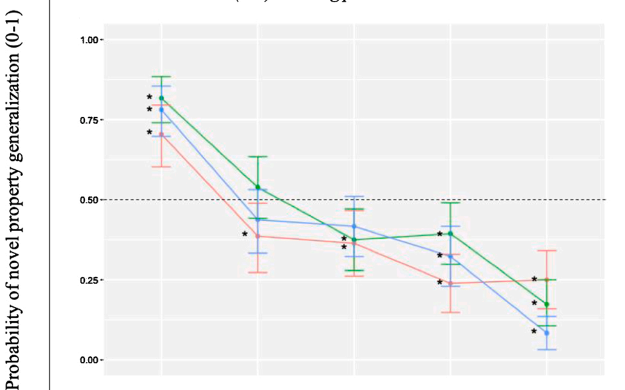
2.3.1. *Follow-up similarity test*

As explained in the introduction, the suspected influence of food processing on children's inductions is potentially twofold. Food processing implies an alteration of the shape of the foods. Such an alteration of the visual appearance of the test food stimuli might lead to perceptual similarities or dissimilarities between the training stimuli and the test stimuli that could impact children's and adults' inductions. However, food processing might also convey functional information (e.g. functional affordances, intended functions) that might also explain an observed influence of food processing on children's inductions. In order to decide which mechanism has to be favored to explain the influence of food processing on inductions, we conducted a follow-up online test. In the online test, adults were instructed to assess the global perceptual similarity between two stimuli on a seven point Likert scale (1 = "not similar at all" to 7 =

a. *Unprocessed Food (F0) training picture*



b. *Natural kind (NK) training picture*



c. *Artifact (A) training picture*

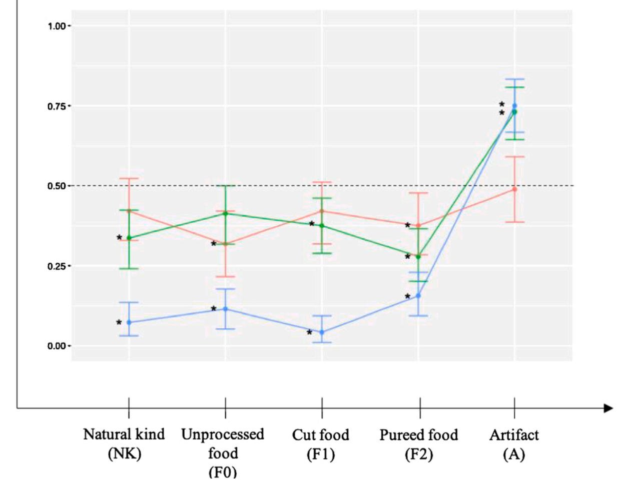


Fig. 2. Probability of property generalization depending on training picture type, test picture type and age.
*Note. Error bars represent confidence intervals. * indicates that performances were different from chance level (Wilcoxon p < .05).*

Table 3

Descriptive for probability of property generalization depending on training picture type, test picture type and age.

	Training F0					Training NK					Training A				
	F0	F1	F2	NK	A	F0	F1	F2	NK	A	F0	F1	F2	NK	A
4- to 5-year-olds	0.53	0.42	0.38	0.35	0.32	0.39	0.36	0.24	0.70	0.25	0.32	0.42	0.38	0.42	0.48
	(0.5)	(0.49)	(0.49)	(0.48)	(0.47)	(0.49)	(0.48)	(0.43)	(0.46)	(0.44)	(0.47)	(0.50)	(0.49)	(0.50)	(0.50)
6- to 7-year-olds	0.64	0.63	0.37	0.57	0.15	0.54	0.38	0.39	0.82	0.17	0.41	0.38	0.28	0.34	0.73
	(0.48)	(0.49)	(0.48)	(0.50)	(0.36)	(0.50)	(0.49)	(0.49)	(0.39)	(0.38)	(0.49)	(0.49)	(0.45)	(0.47)	(0.45)
Adults	0.69	0.60	0.51	0.48	0.14	0.44	0.42	0.32	0.78	0.08	0.11	0.04	0.16	0.07	0.75
	(0.47)	(0.49)	(0.50)	(0.34)	(0.50)	(0.50)	(0.50)	(0.47)	(0.42)	(0.28)	(0.32)	(0.20)	(0.36)	(0.26)	(0.44)
All ages	0.62	0.56	0.42	0.47	0.20	0.46	0.39	0.33	0.77	0.17	0.28	0.28	0.27	0.27	0.66
	(0.48)	(0.50)	(0.49)	(0.50)	(0.40)	(0.50)	(0.49)	(0.47)	(0.42)	(0.37)	(0.45)	(0.45)	(0.44)	(0.45)	(0.47)

Note. Standard deviations are provided in parentheses.

"extremely similar"). Participants were presented with 27 food pairs constituted by 9 F0-F0 (unprocessed-unprocessed), 9 F0-F1 (unprocessed-cut), 9 F0-F2 (unprocessed-pureed). The presentation order of the pairs was fully randomized across participants.

2.4. Scoring and statistical analyses

Children were presented with 30 trials in total (for each of the six blocks, they saw five *test pictures*). For each trial, a score of 1 was given when children generalized the novel property to the *test picture* and placed it to the corresponding box, and a score of 0 was given when the participant did not generalize the property to the *test picture* and placed it in the corresponding box. We tested our predictions with a generalized linear mixed-effects model, using a *Binomial* distribution, to analyze the probability of generalizing the novel property, using the lme4 package, function glmer, in the R environment (Bates et al., 2013). As we were interested in participants' inductive strategies within the three distinct domains of knowledge and how they compare with previous findings, three separate analyses were conducted, one for each *training picture* type (Unprocessed Food, Natural Kind and Artifact). In all models, participants served as a random factor to account for shared variances within subjects. Test Picture Type (Natural Kind [NK], Artifact [A], Unprocessed Food [F0], Cut Food [F1], Pureed Food [F2]) and Age (Younger children [4−5 years], Older children [6−7 years], Adults) were modeled as fixed effects. Preliminary analysis revealed no effects of Property Type (Essential, Functional) nor an interaction with Test picture Type or individual level of food rejection (as measured with the CFRS, Rioux et al., 2017b), thus these variables were not included further in the analyses. To estimate the effect of the specific Test Picture Type and Age on property generalization patterns, we calculated contrasts between the different Test Picture Types and Age using the multicomp package function glth (Hothorn et al., 2014). We report the ANOVA output results for the models throughout. The Post-hoc Tukey comparisons in the text report the optimal model values and all reported tests use Bonferroni-corrected alpha levels to account for multiple comparisons. We reported Bonferroni-corrected significant comparisons, only if at least one generalization value in the comparison was significantly different from chance level as assessed with a Wilcoxon's test (i.e. we did not report differences between two random choices, see Fig. 2a).

For the follow up online study, for each pair-type (i.e. F0-F0, F0-F1, F0-F2), we computed a perceptual similarity score based on participants' responses. We then conducted Wilcoxon tests to determine whether the similarity means characterizing each sub-food conditions were significantly different from each other.

3. Results

Descriptive statistics are provided in Table 3.

3.1. Generalization pattern when the training picture is an Unprocessed Food (F0)

The results revealed a significant effect of Test Picture Type ($\chi2(4) = 111.036$, $p < .0001$). The results also revealed a significant interaction effect between Test Picture Type and Age, $\chi2(8) = 32.88$, $p < .0001$. No significant effect of Age was found ($p = 0.15$). Results are depicted in Fig. 2a.

Regarding the main effect of Test Picture Type, participants generalized significantly fewer novel properties when the *test picture* was an artifact (A) compared to all other Test Picture Types: natural kind, (NK) ($z = 6.63$, $p < .0001$), unprocessed food (F0) ($z = 9.45$, $p < 0.0001$), cut food (F1) ($z = 8.48$, $p < .0001$), and pureed food (F2) ($z = 5.68$, $p < 0.0001$). Participants generalized significantly more the novel properties when the *test picture* was an unprocessed food (F0) as compared to a natural kind (NK) ($z = 3.93$, $p < .0001$) and pureed food (F2) ($z = 5.00$, $p < .0001$). Finally, participants generalized significantly more often the novel properties when the *test picture* was a cut food (F1) compared to a pureed food (F2) ($z = 3.25$, $p = 0.00012$). Generalization values across ages are reported in Table 3.

Regarding the interaction effect of Test Picture Type and Age, older children (6−7 years) generalized significantly fewer the novel properties when the *test picture* was a tool (A) (below chance level, $p < 0.0001$), as compared to all other Test picture Types: natural kind (NK) ($z = 5.98$, $p < .0001$, not different from chance), unprocessed food (F0) ($z = 6.86$, $p < 0.0001$, above chance level, $p = 0.0033$), cut food (F1) ($z = 6.65$, $p < .0001$, above chance level, $p = 0.011$) and pureed food (F2) ($z = 3.45$, $p = .00057$, below chance level, $p = 0.0061$). Older children also generalized significantly fewer novel properties when the *test picture* was a pureed food (F2) compared to unprocessed food (F0) ($z = 4.04$, $p < .0001$) and cut food (F1) ($z = 3.77$, $p = 0.00016$). Similarly, adults generalized significantly fewer novel properties when the *test picture* was a tool (A) (below chance level, $p < 0.0001$) compared to all other Test Picture Types: natural kind (NK) ($z = 4.98$, $p < .0001$, not different from chance), unprocessed food (F0) ($z = 7.25$, $p < .0001$, above chance level, $p = 0.00024$), cut food (F1) ($z = 6.36$, $p < .0001$, above chance level, $p = 0.041$) and pureed food (F2) ($z = 5.34$, $p = .00057$, not different from chance). Table 4 summarizes the significant differences reported above.

3.2. Generalization pattern when the training picture is a Natural Kind (NK)

The results revealed a significant effect of Test Picture Type, $\chi2(4) = 193.91$, $p < .0001$. The results also revealed a significant interaction effect between Test Picture Type and Age, $\chi2(8) = 17.22$, $p = .028$. No effect of Age was found ($p = 0.083$). Results are depicted in Fig. 2b.

Firstly, regarding the main effect of Test Picture Type, participants generalized significantly more often the novel properties when the *test picture* was a natural kind (NK) compared to all other Test Picture Types: artifact (A) ($z = 13.05$, $p < .0001$), unprocessed food (F0) ($z = 7.63$, $p < 0.0001$), cut food (F1) ($z = 9.08$, $p < 0.0001$) and pureed food (F2) ($z = 10.42$, $p < .0001$). Participants made fewer

Table 4
Main significant differences revealed from the interaction effect between Test picture Type and Age.

Unprocessed Food (F0) training picture			Natural Kind (NK) training picture			Artifact (A) training picture		
4–5 years			4–5 years	NK	F0			
					F1			
					F2			
					A			
6–7 years	A	NK	6–7 years	NK	F0	6–7 years	A	NK
		F0			F1			F0
		F1			F2			F1
		F2			A			F2
	F2	F0		A	F0			
		F1			F2			
Adults	A	NK	Adults	NK	F0	Adults	A	NK
		F0			F1			F0
		F1			F2			F1
		F2			A			F2
				A	F0			
					F1			
					F2			

Note. The table is read as follow: when the training picture was an unprocessed food (left column), 4-to 6-year-old children generalized significantly differently the novel properties for the pureed food test picture (F2) compared to the unprocessed food test picture (F0) and the cut food (F1) test picture (first row).

generalizations of novel properties when the *test picture* was an artifact (A) compared to an unprocessed food (F0) (z = 7.26, $p <$ 0.0001), cut food (F1)($z = 5.87, p < 0.0001$), and pureed food (F2) ($z = 4.29, p < .0001$). Finally, participants generalized significantly more often the novel properties when the *test picture* was an unprocessed food (F0) compared to pureed food (F2) (z = 3.41, p = .00065). Generalization values across ages are reported in Table 3.

Secondly, regarding the interaction effect of Test Picture Type and Age, younger children (4–5 years) generalized significantly more often and above chance level ($p = 0.00013$) the novel properties when the *test picture* was a natural kind (NK), compared to all other Test Picture Types: artifact (A) ($z = 6.02, p < .0001$, below chance $p < 0.0001$), unprocessed food (F0) ($z = 4.26, p < .0001$, below chance $p = 0.033$), cut food (F1) ($z = 4.52$, $p < .0001$, below chance $p = 0.011$) and pureed food (F2) ($z = 6.02$, $p < .0001$, below chance $p < 0.0001$). The same results were observed for older children (6–7 years), who generalized significantly more often the novel properties when the *test picture* was a natural kind (NK) (above chance level, $p < 0.0001$) compared to all other Test Picture Types: artifact (A) ($z = 8.55, p < .0001$, below chance $p < 0.0001$), unprocessed food (F0) ($z = 4.25, p < .0001$, no different from chance), cut food (F1) ($z = 6.28$, $p < .0001$, below chance $p = 0.011$) and pureed food F2 ($z = 6.04$, $p < .0001$, below chance $p = 0.031$). Older children also generalized the novel property significantly less when the *test picture* was an artifact (A) compared to unprocessed food (F0) ($z = 5.36$, $p < .0001$) and pureed food (F2) ($z = 3.51$, $p = .00045$). Finally, similar to children, adults generalized significantly more the novel properties when the *test picture* was a natural kind (NK) (above chance level, $p < 0.0001$) compared to all other Test Picture Types: artifact (A) ($z = 8.38$, $p < .0001$, below chance $p < 0.0001$), unprocessed food (F0) ($z = 4.82$, $p < .0001$, no different from chance), cut food (F1) ($z = 5.08, p < .0001$, no different from chance) and pureed food (F2) ($z = 6.20, p < .0001$, below chance $p =$ 0.00052). Adults also generalized the novel properties significantly less when the *test picture* was an artifact (A) compared to unprocessed food (F0) ($z = 5.17$, $p < .0001$), cut food (F1) ($z = 4.94$, $p < .0001$) and pureed food (F2) ($z = 3.92$, $p = .00057$). Table 4 summarizes the significant differences reported above.

3.3. Generalization pattern when the training picture is an Artifact (A)

The results revealed a significant effect of Test Picture Type, $\chi2(4) = 145.514$, $p < .0001$. The results also revealed a significant effect of Age, $\chi2(2) = 43.92, p < .0001$. Finally, the results demonstrated a significant interaction effect between Test Picture Type and Age, $\chi2(8) = 70.10$, $p < .0001$. Results are depicted in Fig. 2c.

With regards to the main effect of Test Picture Type, participants generalized the novel properties significantly more when the *test picture* was an artifact (A), compared to all other Test Picture Types: natural kind (NK) ($z = 9.12, p < .0001$), unprocessed food (F0) ($z =$ 9.07, $p < .0001$), cut food (F1) ($z = 8.76$, $p < .0001$) and pureed food (F2) ($z = 9.29$, $p < .0001$).

Regarding the main effect of Age, adults generalized the novel properties significantly less when compared to younger children ($z =$ 5.68, $p < .0001$) and older children ($z = 6.32$, $p < .0001$). Generalization values across ages are reported in Table 3.

Finally, regarding the interaction effect of Test Picture Type and Age, older children generalized the novel properties significantly more when the *test picture* was an artifact (A) (above chance level, $p < 0.0001$) compared to all other Test Picture Types: natural kind (NK) ($z = 5.99, p < .0001$, below chance $p = 0.00086$), unprocessed food (F0) ($z = 4.67, p < .0001$, no different from chance), cut food (F1) ($z = 5.18$, $p < .0001$, below chance $p = 0.11$) and pureed food (F2) ($z = 6.45$, $p < .0001$, below chance $p < 0.0001$). The same results were observed for adults, who generalized the novel properties significantly more when the *test picture* was an artifact (A) (above chance level, $p < 0.0001$), compared to all other Test Picture Types: natural kind (NK) ($z = 8.22, p < .0001$, below chance $p <$ 0.0001), unprocessed food (F0) ($z = 8.14, p < .0001$, below chance $p < 0.0001$), cut food (F1) ($z = 7.82, p < .0001$, below chance $p <$ 0.0001), and pureed food (F2) ($z = 7.81$, $p < .0001$, below chance $p < 0.0001$). Adults also generalized significantly more the novel properties to natural kinds (NK) and cut foods (F1), than younger children ($z = 4.91$, $p < .0001$ and $z = 5.10$, $p < .0001$, respectively for NK and F1) and older children ($z = 4.21$, $p < .0001$ and $z = 4.84$, $p < .0001$, respectively for NK and F1). Finally, adults generalized significantly more often the novel properties to unprocessed foods (F0), than older children ($z = 4.54$, $p < .0001$) and the novel properties to artifacts (A), than younger children ($z = 3.48$, $p = .00051$). Table 4 summarizes the main significant differences reported above.

3.4. Comparison of the three food pair types with respect to perceptual similarity

We computed the perceptual similarity means for each food pair type: unprocessed food-unprocessed food (F0-F0), ($M = 3.13$, $SD = 1.04$), unprocessed food-cut food F0-F1 ($M = 2.46$, $SD = 0.77$), unprocessed food-pureed food (F0-F2) ($M = 2.10$, $SD = 0.75$). Overall, these means were low, but significantly different from each other as attested by Wilcoxon tests: unprocessed food-unprocessed food/ unprocessed food-cut food (F0-F0/F0-F1) ($V = 1610$, $p < 0.0001$); unprocessed food/unprocessed food/unprocessed food-unprocessed food-pureed food (F0-F0/F0-F2) ($V = 1956$, $p < 0.0001$); unprocessed food-cut food/unprocessed food-pureed food (F0-F1/F0-F2) ($V = 1476$, $p < 0.0001$). See Table 5.

4. Discussion

4.1. Four to 5-year-olds exhibited less differentiated inductive reasoning strategies between natural kind, food, and artifact domains of knowledge than 6- to 7-year-olds and adults

The results confirm that older children exhibited highly specific inductive reasoning strategies within the tested categories in our study, while younger children made fewer principled distinctions among them (Hypothesis 1). Indeed, older children generalized both essential and functional properties almost systematically and significantly differently according to the type of training and test pictures. Expanding upon previous findings (e.g., Gelman, 1988), older children clearly distinguished natural kind from artifact categories in the inductions they made. When the training picture was a natural kind or an artifact, the probability of generalizing the property was significantly higher for natural kind and artifact test pictures respectively, as compared to test pictures belonging to the other domains. The patterns of induction of the older children across all domains were similar to those observed in the adult control group with the exception of a noticeable difference in responses for the pureed food (F2; see section below).

Congruent with previous findings on the development of induction patterns (e.g., Gelman, 1988), the younger children made few principled distinctions among the different categories we manipulated, compared to older children. The probability of generalizing the property was significantly higher for natural kind test pictures compared to test pictures belonging to other domains only when the training picture was a natural kind. In a further experiment, it would be worth replicating this intriguing result for other natural kind categories varying in *complexity,* such as substances or animals (Gelman, 1988; Keil, 1989 for discussion of the complexity variable within the natural kind domain).

4.2. Six and 7-year-olds' inductive reasoning strategies were only partly impacted by the degree of processing of the food test stimuli

From these results we cannot firmly conclude that the different stages of food processing had a clear impact on induction strategies for any of the age group we tested (Hypothesis 2). However, the Post-hoc Tukey comparisons revealed that for the older children, when the training picture was an unprocessed food (F0), the probability of generalizing the property to a pureed food (F2) was significantly higher than for an artifact (A), but significantly lower than for unprocessed and cut foods (F0 and F1, respectively). This pattern is specific to older children (6–7 years) only, as adults generalized the property to pureed foods (F2) as for unprocessed foods (F0) and cut foods (F1).

As we mentioned in the introduction, food processing generally implies changes to visual appearance, and especially shape. This suggests that the differences we observed between unprocessed food-cut food (F0-F1) and unprocessed food-pureed food (F0-F2) for older children might be due to the fact that cut foods (F1) are more perceptually similar to unprocessed foods (F0) than pureed foods (F2) to unprocessed foods (F0). Although this is precisely what we found in the follow-up online study with adults, it is important to emphasize that such an interpretation that the observed effect of food processing would be due to a confounding influence of perceptual similarity is unlikely for two reasons. The first reason is that the means of perceptual similarity for each food pair type, though significantly different from each other as attested by the Wilcoxon tests, are low. It is thus unlikely that the perceptual

Table 5

Means perceptual similarity scores, standard deviation, and comparisons for each food pair type.

Food pair type	Mean	Standard Deviation
F0-F0	3.13***	1.04
F0-F1	2.46***	0.77
F0-F2	2.10***	0.75

Note. * for $p < 0.01$; ** for $p < 0.001$; *** for $p < 0.0001$. Test reported in the Table are Wilcoxon tests to examine whether the three similarity means were significantly different from each other.

similarities or dissimilarities were salient enough to constrain the inductions of the older children.

The second reason is that if perceptual similarities were responsible for the observed influence of food processing on older children's inductions, we should have observed such influence, even to a greater extent, on younger children's inductions as well. Indeed, recent studies have suggested that children, especially children about 3 years of age rely on perceptual similarity in the food domain instead of taxonomic category membership (Rioux et al., 2017a).

Therefore, even if the results of the present experiment allow us to draw only provisory conclusions about the nature of the influence of food processing, the pattern of induction in older children provides the foundation for further exploration. Indeed, this pattern does not seem to result from a confounding influence of perceptual similarity or dissimilarity. It is consistent with the general idea that the more the food is processed, the closer it becomes to a human-made entity, and therefore, more distant from the domain of a naturally occurring entity. In other words, we suspect that food processing might lead children to detect or infer functional properties (e.g. edibility) and derive human agency (i.e. intended functions) that move these food items away from the domain of naturally occurring entities and closer to human-made entities on the putative natural kind-artifact continuum. Further research is of course needed to refine and test this hypothesis.

4.3. Limitations and perspectives

Firstly, in the present study, the property type was manipulated (essential versus functional) in order to test the hypothesis that the generalization of an essential property (e.g. "made of zuline") should be facilitated within the domain of naturally occurring entities, as compared to the domain of human-made objects. Reciprocally, we expected a facilitation of the generalization of functional properties (e.g. "zulinizes the heart") within the artifact domain when compared to the natural kind domain. Our analyses did not reveal any effect of the property type on inductive reasoning strategies in the three populations of interest, contrary to what Gelman (1988) observed for older children. The absence of any observable influence of the property type might be imputable to the fact that we used novel properties to prevent any influence of background knowledge on induction strategies. It is possible that constraining only syntactically the property (*made of x* versus *x[izes] something*) was not sufficient to force the interpretation of our novel properties as essential versus functional. This issue could be addressed in further experiments by providing a sentential context to facilitate the interpretation of the property conditions, especially in younger participants.

Furthermore, in the present study the participants had to generalize the property not at a basic level, but at a superordinate level of categorization, and existing empirical evidence is partly conflicting as to the defining properties attributed at that level of abstraction. Indeed, Gelman (1988)'s results confirmed that second graders generalized functional significantly more than essential properties in the artifact condition, but only at a basic level. Interestingly, when it came to generalization within the natural kind domain at a *superordinate level,* second graders generalized more functional properties than essential ones. Gelman (1988) interpreted this unexpected result as the sign that functional properties may likely characterize a superordinate category, even if their extension corresponds to a set of naturally occurring entities. Further research is thus needed to determine the defining properties of different superordinate categories from a child's perspective.

The younger children's inductions were often close to chance, possibly because they were asked to base their induction on superordinate category membership (e.g. food versus natural kind), which might have been too demanding for them. Therefore, we cannot firmly conclude that the present results reflect younger children's lack of "differentiation" between domains since other interpretations are plausible. Indeed, younger children might have exhibited less differentiated inductive reasoning strategies because the task was too demanding and led them to generalize a property randomly. A promising way to determine which interpretation is the right one would be to remove some ambiguity from the task by presenting the training food and then cut and pureed (F1 and F2) test items with some general labeling using demonstratives or indexicals (e.g. "here is the same food that's been cut up"; "here is the same food that's been mashed"). In so doing, the inductions of the younger children could move above the level of chance in more conditions, which in turn could render the comparisons of patterns of induction within and between the domains of knowledge more informative.[2]

Furthermore, in the present study we manipulated the level of food processing by manipulating only shape properties. However, other recent studies relied on a richer notion of food processing or transformation justified by evolutionary considerations (Foroni, Pergola, & Rumiati, 2016). Indeed, food processing has been defined not only as a shape transformation, but also as implying a modification of the organoleptic properties of the initial food along with a subsequent energetic advantage for survival (Carmody & Wrangham, 2009; Wrangham & Conklin-Brittain, 2003). According to this approach, food processing is a reliable cue for assessing food quality (i.e. arousal and perceived energy density), and specifically food processing with cooking is understood as a major step in human evolution (Foroni et al., 2016; see also Rumiati and Foroni, 2016; Carmody, Weintraub, & Wrangham, 2011; Fonseca-Azevedo & Herculano-Houzel, 2012; Wrangham et al., 1999). Going back to the present study, it is arguable that our food stimuli do not exhibit different degrees of food processing according to this more demanding definition involving an energetic advantage after the transformation occurred. Thus, a strategy worth investigating in further experiments would be to manipulate the degree of food processing in this broader sense to determine if it affects food categorization and induction in young children[3] .

Results did not reveal any influence of the food rejection tendencies (i.e. neophobia and picky fussy/eating dimensions, Lafraire et al., 2016) on inductive reasoning strategies in children. At first, it appears surprising that the analyses did not reveal an influence of food rejection tendencies, since moderate differences had been observed in a study testing inductive reasoning *performance* in

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[2] We would like to acknowledge an anonymous reviewer for having recommended this strategy for further research.

[3] We are grateful to an anonymous reviewer for having stressed that point.

preschoolers on unfamiliar stimuli (Rioux et al., 2018). However, Rioux and colleagues used a conflicting triad paradigm pitting taxonomic category membership against perceptual similarity (see Gelman & Markman, 1986 for a similar paradigm). Therefore, they were relying on the standard assumption that the correct answer for such a task is the taxonomic match rather than the perceptual match, which suggests that neophobic and picky children have a less mature conceptual system leading to poor inductive performance compared to their neophilic peers. The present study was not grounded in such an assumption. Indeed, the present study can be read as a conceptual replication of Gelman (1988), extending it by investigating children's' patterns of induction in the food domain (see Fig. 2 and Table 3) at a superordinate level. Therefore, evidence generated here does not conflict with evidence obtained by Rioux and colleagues since we focused on children's induction strategies rather than on performance.

Finally, the present study has potential implications for knowledge-based food education interventions to foster dietary variety among preschoolers. These novel type of health interventions, contrary to interventions relying on forms of nudging or conditioning (e.g., Havermans & Jansen, 2007), aim, *at first*, on improving young children's knowledge rather than seeking behavioral change *per se*, in order to foster dietary variety. Such interventions have been shown to efficiently achieve this goal. For instance, interventions that capitalize and enrich children's early food knowledge impact positively children's food behavior and preferences (Gripshover & Markman, 2013; Nguyen, McCullough, & Noble, 2011) and opens a very promising way to face the challenge of healthy eating in young children. These interventions focus on providing children new facts about the food items. Interestingly, these facts generally are about foods as a source of nutrients (generally presented as invisible food insides) combined with causal/biological explanations to help children to understand food and body relationships. In so doing, proponents of these interventions aim to tap into children's naïve theories on biology (Inagaki & Hatano, 2006; 1992; 1997).

Yet, to develop a full-fledged food education programs, the facts communicated to the children should not only be about untransformed food, but about transformed food as well, as they are ubiquitous in children daily life. However, if transformed foods are not considered as natural kinds, but rather partly human-made (as our results suggest) then referring to insides, essential nutritional properties, and biological processes might not be the most efficient way to convey facts about them to children. Referring to intended function (of a chef for instance) and functional features associated with culinary transformation (e.g. flavor enhancement, contexts of consumption) could be a far more efficient way to teach a theory of processed foods (see also Girgis & Nguyen, 2018). Furthermore, evidence-based programs about transformed foods could lead to increasing knowledge of food outside of their corresponding essential properties. Thematic or script food properties (e.g. is eaten at lunch time, see Nguyen, 2007 for a discussion of script and thematic categories) have been shown to be more often associated with transformed foods (Pergola et al., 2017; Rumiati and Foroni, 2016; Warrington & Shallice, 1984[4]) than to natural food in adults. These neuropsychological studies combined with the results of the present study support future research in nutrition-based interventions supplemented with different types of conceptual information. In other words, all the facets of the food domain are worth explaining to the children but, because of the hybrid nature of the food domain itself, some foods possibly require a more in-depth explanations about how they were created or made.

5. Conclusion

The present study revealed differentiated inductive reasoning strategies between natural kind, food, and artifact domains of knowledge in children from 6- to 7- years of age. In addition, results suggest an influence of food transformation on these older children's inductions. Food stimuli have been classically used as natural kind exemplars, but the present results may encourage researchers interested in conceptual development to take into account the specificities of the food domain, as well as its intriguing ambiguity with respect to the natural kind-artifact distinction.

Furthermore, the shared assumption that foods are natural kind entities seemed to have shaped the way promising evidence-based food education interventions have been designed so far. By casting a reasonable doubt on this assumption, the results of the present study invite researchers in the field of food cognition to explore a variety of food knowledge structures to boost children's category-based inductions in the food domain.

Declaration of Competing Interest

None.

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[4] Rumiati & Foroni and Pergola and colleagues refer to thematic or script relations (e.g. is eaten at lunch time) as "functional features" or "functional information", this difference of terminology should not mask the interest of these neuropsychological studies for our topic here.

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