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Une approche des rejets alimentaires chez les jeunes enfants par la catégorisation et les fonctions exécutives.

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Titre : Une approche des rejets alimentaires chez les jeunes enfants par la catégorisation et les fonctions exécutives.

Mots clés : néophobie alimentaire ; sélectivité alimentaire ; jeunes enfants ; développement cognitif ; connaissances conceptuelles ; fonctions exécutives.

Résumé : La néophobie et la sélectivité alimentaires font obstacle à la consommation de fruits et de légumes, pourtant nécessaires à un régime qui facilite un développement normal et sain. Il est crucial d'étudier les fondements cognitifs de ces rejets afin de permettre l'adoption de comportements sains. Le rejet alimentaire semble en partie conditionné par les connaissances qu'ont les enfants des aliments. Les connaissances permettent la reconnaissance d'un aliment, de le catégoriser et de prendre des décisions fondées sur ses propriétés et les conséquences possibles de sa consommation. Dû à un manque de connaissances, des stimuli ou des situations alimentaires peuvent apparaître incertains. Cette incertitude augmente la probabilité qu'un aliment soit rejeté, qu'il soit comestible ou précédemment accepté mais préparé différemment. Pour lutter contre les rejets alimentaires, des interventions tentent d'accroître les connaissances des enfants par le biais de programmes éducatifs ou d'expositions répétées à des aliments.

Cependant, les effets de ces interventions sont limités pour les enfants très néophobes et sélectifs. Des rejets élevés ont été associées à des réponses émotionnelles et physiologiques fortes, similaires à des réactions phobiques. Cette peur peut inhiber la capacité d'apprentissage des enfants. Par conséquent, ils peuvent éprouver des difficultés pour développer leurs connaissances des aliments. En effet, d'après de précédentes recherches, l'intensité des rejets des enfants est inversement liée à leurs connaissances des catégories alimentaires.

Dans ce contexte, le premier objectif de cette thèse était d'étudier les deux influences apparentes des rejets : les lacunes dans les connaissances alimentaires et les stratégies d'évitement, conditionnées par la peur des situations alimentaires incertaines. La variable de transformation alimentaire a également été manipulée pour tester l'hypothèse selon laquelle les enfants utiliseraient des indices visuels tels que le tranchage pour surmonter leur peur. Les résultats ont révélé que les rejets alimentaires étaient liés à une diminution des performances de catégorisation et à une prudence accrue. Les enfants néophobes et sélectifs étaient plus prudents et, par rapport à leurs pairs néophiles et non-sélectifs, ne s'appuyaient pas sur la variable de transformation comme indice de sécurité. Pour développer les connaissances de ces enfants il semble nécessaire de commencer par surmonter leur peur d'une situation d'apprentissage avec des aliments.

Son second objectif était d'étudier si les fonctions exécutives étaient impliquées dans les rejets alimentaires. Des fonctions exécutives sous-développées expliqueraient les difficultés des enfants néophobes et sélectifs à extraire l'information des situations d'apprentissage, leurs comportements rigides envers les nouveaux aliments ou la préparation des repas, et l'utilisation de leurs connaissances antérieures. Les études ont révélé des relations négatives entre les rejets alimentaires et les fonctions exécutives, précisément une diminution de l'inhibition et de la flexibilité cognitive. La flexibilité cognitive a également un rôle médiateur dans la relation entre les rejets alimentaires et les capacités de catégorisation. Les fonctions exécutives sont donc importantes dans les comportements alimentaires, directement et indirectement, sur la capacité des enfants à développer des connaissances.

La thèse contribue à la compréhension du développement des rejets alimentaires chez les jeunes enfants et met en lumière différents facteurs influençant les capacités d'apprentissage dans le domaine alimentaire. Cette contribution est précieuse pour notre compréhension des difficultés des enfants néophobes et sélectifs à apprendre et à agir de manière appropriée avec les aliments et pour le développement d'interventions visant à améliorer leurs habitudes alimentaires.

Title: A categorization and executive functions approach of food rejection in young children.

Keywords: food neophobia; food pickiness; young children; cognitive development; conceptual knowledge; executive functions.

Abstract: Food neophobia and pickiness are two strong psychological obstacles to young children's consumption of fruits and vegetables, which are necessary components of a diet that facilitates normal and healthy development. It is therefore of critical importance to investigate the cognitive underpinnings of these two kinds of food rejection to promote the adoption of healthy eating behaviors. Food acceptance and rejection appear to be partly conditioned by children's knowledge of the food domain. Knowledge allows children to recognize a given food, categorize it, and make inference-based decisions on its properties and possible consequences of consumption. Underdeveloped knowledge may cause food stimuli or situations to appear uncertain. Uncertainty will increase the likelihood of food being rejected, regardless if it is edible or previously accepted under another method of preparation. To tackle food rejection, interventions had, thus, aimed to increase children's familiarity and knowledge through educational-based programs or repeated exposures to target foods.

However, despite overall successes, such interventions had limited benefits for highly neophobic and picky children. High levels of food rejection have been associated with strong emotional and physiological responses, similar to reactions found in phobias. This fear may inhibit children's learning ability. Consequently, neophobic and picky children may be unable to develop their knowledge of the food domain. Previous evidence, indeed, demonstrated that children's food rejection was inversely related to their knowledge of food categories.

In this context, the first objective of the present thesis was to investigate the twofold driver of food rejection: the gaps in food knowledge and the fear-conditioned withdrawal strategies in uncertain food situations. The food processing variable was also manipulated to test the hypothesis that children could rely on visual cues such as slicing to overcome their fear. The results revealed that food rejection was related to decreased categorization performance and heightened caution. Neophobic and picky children over-executed caution and, compared to their more neophilic and less picky counterparts, did not rely upon the variable of food processing as a safety cue. To develop the knowledge of children with high food rejection, it might be first necessary to overcome their fear of the learning situation.

The second objective was to investigate whether executive functions (i.e., working memory, inhibition, and cognitive flexibility) were implicated in food rejection. Underdeveloped executive functions would explain neophobic and picky children's difficulties to extract information from food-related learning opportunities, rigid behaviors toward dietary variety or meal preparations, and appropriate use of previous knowledge. This investigation revealed negative relations between food rejection and executive functions, more precisely decreased inhibition and cognitive flexibility in highly neophobic and picky children. Cognitive flexibility was also found to mediate the relationship between food rejection and categorization abilities. The results add to the body of evidence that executive functions play an important role in food-related behaviors.

The thesis contributes to the understanding of the development of food rejection in young children and sheds light on different factors influencing children's learning ability in the food domain. This contribution is valuable for our understanding of neophobic and picky children's difficulties to learn and to act appropriately about foods and the development of interventions aiming at improving their eating habits.

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GENERAL INTRODUCTION

Let me start with a personal anecdote: at a very early age, my father took me to pick mushrooms. In the beginning, he did not allow me to pick mushrooms by myself. My father wanted to examine them first. I understood that picking mushrooms was a task to carry out with caution. Most of the mushrooms we found were inedible, some even deadly. Each outing was a learning opportunity to develop my knowledge of mushrooms and I became able to identify some mushrooms which were safe. Nonetheless, my knowledge was and is still relatively limited and I do not dare pick mushrooms I do not recognize. For example, determining whether a mushroom is a morchella or a gyromitra remains difficult (Figure 1), I prefer to leave it untouched because even though morchellas are delicious, gyromitras are poisonous.

Figure 1. On the left is a morchella and on the right is a gyromitra

The domain of food is not one of trial and error, as one mistake can be fatal. We start learning from our caregivers. We acquire knowledge regarding what we can and would like to eat. However, it is a timely process and many substances are perceived as novel by young children. For example, even though I found morchellas delicious, I did not dare touch a blond color morchella – instead of black I was used to - the first time I saw one. This avoidance reaction stemming from my fear of picking a poisonous mushroom robbed me of an early opportunity to learn that the blond morchella, like its black sister, is incredibly tasteful. Reactions of fear towards what we do not know, what we are uncertain about, or towards things that are different from what we are used to, are certainly an effective survival mechanism in a domain as dangerous as the one of foods. These reactions have been defined as neophobia (Pliner et al., 1993; Rozin, 1979). However, if this cautiousness is over-executed, it will likely lead to a significant narrowing in opportunities to learn whether to accept potential foods. As shown by Figure 2 (Crane et al., 2020), one has to find a balance between benefits and costs.

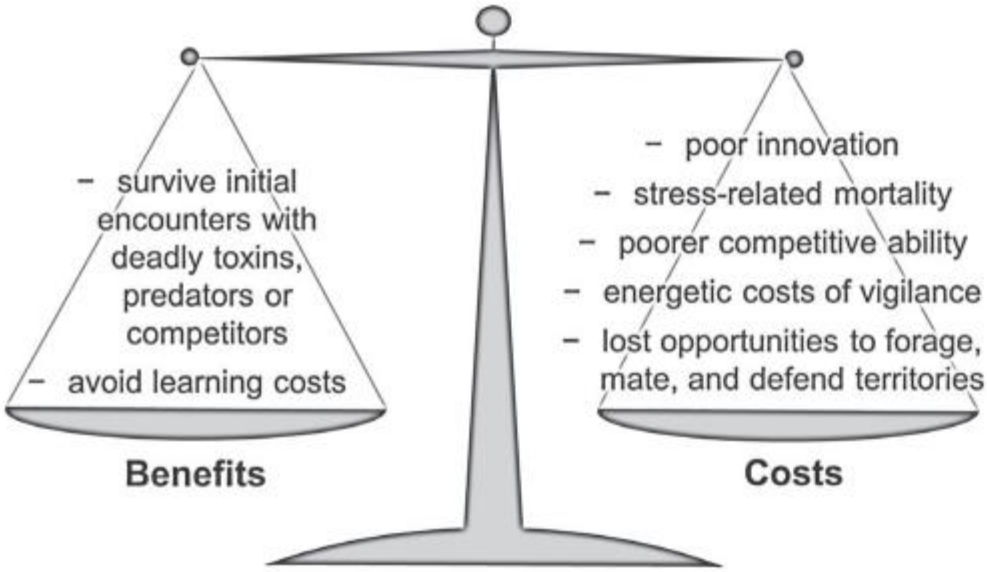

Figure 2. Benefits and costs of neophobia from Crane et al. (2020)

This avoidance of novel foods, often described as “it is not good”, “it will make me sick” by young children who do not even try their food is a well-known phenomenon by caregivers (Johnson et al., 2018). This kind of food rejection refers to food neophobia, also defined as the fear to eat or even try novel foods (Pliner & Hobden, 1992). On the other hand, the rejection of familiar foods or textures refers to food pickiness (Taylor et al., 2015). These two kinds of food rejection dispositions prevent children from ingesting potentially poisonous substances (Cashdan, 1994; Pliner et al., 1993; Rozin, 1979). They might be beneficial in situations of uncertainty about the edibility of a substance (e.g., to not pick an unfamiliar mushroom). However, in situations in which the risk is minimal (e.g., mushrooms bought from a store), these reactions are ill-adapted and may have negative consequences on children’s development. Indeed, severe food rejection has been reported to lead to low consumption of familiar fruits and vegetables (Dovey et al., 2008), which are a necessary component of a diet that facilitates normal and healthy development (Woodside et al., 2013). It is, therefore, essential to investigate the cognitive mechanisms of food rejection in young children to promote compliance to healthy eating behaviors during this critical developmental stage.

Much like I learned to discriminate safe mushrooms from unsafe ones, current nutrition interventions aim to develop children’s knowledge of foods through exposure (L. Cooke, 2007; Keller, 2014) and education-based programs (Weisman & Markman, 2017). However, children with high food rejection may continue refusing to eat the foods they had been exposed to, which may discourage caregivers from continuing to present foods repeatedly rejected. Consequently, the opportunities to learn about these foods may be greatly reduced. Unable to learn about the foods, when presented at a later time, they might appear as novel and thus elicit feelings of fear, resulting in further rejection. Therefore, the relationship between food rejection and knowledge is likely cyclical (i.e., food rejection leads to decreased exposures which prevent children from developing knowledge about different foods, thus when subsequently presented they might be rejected, and so on; Rioux et al., 2016; 2017a).

Is it possible to break this vicious circle? i) To answer this ambitious question the current thesis proposes a more indirect solution than direct exposure to novelty, situations that can invoke feelings of fear or anxiety in some children. Our research empirically investigated whether visual cues of food processing could reduce children's uncertainty that a substance is safe to consume. ii) A second ambition of the thesis is to propose a redefinition of the vicious circle problem. Currently, the problem is defined as gaps of knowledge promoting uncertainty that, in turn, leads to food rejection, making filling those gaps a challenge. We hypothesized that, instead, the problem may arise from children's difficulties to use appropriately their knowledge of food. More precisely, the research empirically tested whether food rejection was related to poorer executive functions. If children lack the necessary executive functions to adapt to novel stimuli and to reason on the most relevant information in a given context, they would be unable to use their knowledge appropriately. For example, when I abandoned the morchella because it was blond and not black if i) instead of having encountered the mushroom in its natural state, it had been served on a plate prepared by a cook, I may not have doubted its edibility; and if ii) instead of focusing my attention on its color which in this case was not informative, had I focused on its cap that looks like honeycombs, I may have identified the mushroom as a morchella.

In an attempt to test these hypotheses, I describe first in Part A the theoretical framework of my thesis. Chapter 1 outlines the literature relating to the cyclical relationship between food rejection and conceptual development. Chapter 2 provides arguments for children's use of cues of food processing to tackle food rejection. Chapter 3 presents a redefinition of the circle from an executive functions perspective. Finally, Chapter 4 outlines the objective, hypotheses, and methodologies of my empirical research divided into Part B and Part C.

Part B contains two chapters (5 and 6) related to Chapter 2, testing the food processing hypothesis. Chapter 5 presents a study, exploring the relationship between food neophobia and the generalization of food properties (i.e., positive and negative) to other foods. Chapter 6 includes two food-versus-nonfood categorization tasks testing for children's strategy to categorize as edible stimuli based on their processing state.

Part C also contains two chapters (7 and 8) related to Chapter 3, testing the executive functions hypothesis. Chapter 7 introduces a first study investigating the relations between food rejection and executive functions. Chapter 8 builds upon findings in Chapter 7, extended with performance on two different categorization tasks.

Finally, Part D, a general discussion gives an overview and discussion of the thesis as a whole, including a summary of the main findings and the contribution to the current understanding of the relationship between food rejection and conceptual knowledge.

PART A. THEORETICAL FRAMEWORK

Chapter 1. Food rejection and food conceptual knowledge: a vicious circle

1.1. Food rejection, a fear of the unknown

The notion of food rejection embraces two distinct, though related, dispositions: food neophobia and pickiness. Before discussing the relationship between food rejection and conceptual knowledge, definitions of these dispositions will be provided.

1.1.1. Food neophobia

Food neophobia refers to the reluctance to eat or even try foods that appear novel (Pliner & Hobden, 1992). Most researchers agree that food neophobia peaks between 2 and 6 years of age (Carruth et al., 2004; Cashdan, 1994; Dovey et al., 2008; Dubois et al., 2007; Lafraire et al., 2016a; Mascola et al., 2010). Before the neophobic onset, children are very willing to accept foods, even new ones, especially from caregivers. After the neophobic onset, children are not only less likely to taste new foods, but even foods that have been previously accepted may well be rejected. Numerous studies have demonstrated that food neophobia is a true phobia (see Maratos & Sharpe, 2018 for a review). For instance, it has been shown that individuals with high levels of neophobia display stronger typical physiological fear responses to new foods, such as galvanic skin response and an increase in pulse or respiration rhythm, as compared to their neophilic counterparts (Raudenbush & Capiola, 2012). Furthermore, food neophobia is often connected to an increase in anxiety (Galloway et al., 2003), or even disgust over new foods (Brown & Harris, 2012; Martins & Pliner, 2006). Recently, Maratos and Staples (2015) showed that, although all children demonstrate attentional biases (e.g., facilitated visual engagement) toward new foods, these biases were heightened in children displaying higher levels of food neophobia. All three components (anxiety, disgust, or attentional biases) are standard markers of phobias (Cisler & Koster, 2010). Other findings on the expectations (e.g., danger) associated with novel foods support the idea that food neophobia represents a genuine fear response (e.g., Johnson et al., 2018; Pliner et al., 1993). For instance, Johnson et al. (2018) asked children between 3 and 5 years of age their reasons to avoid tasting novel foods. More than half of children’s justifications referred to the fear of negative consequences following ingestion (e.g., nausea, falling sick, choking, dying). An additional finding of their study is that neophobic children (i.e., children less willing to try the new foods in the experiment) rated the foods less favorably than more neophilic children. Prototypically, neophobic children categorically refuse to even try novel food, despite caregivers’ efforts. Even a dish or a meal may be avoided if a novel food is present (Ton Nu, 1996). Critically, a neophobic rejection occurs on sight, before a new food enters the mouth.

1.1.2. Food pickiness

On the other hand, rejections based on hedonic evaluations leading to a substantial narrowing of a diet, limited to a range of preferred foods, fall inside the scope of food pickiness (Taylor et al., 2015). Food pickiness is believed to be a transitory and age-related phenomenon (Dovey et al., 2008). Despite, contention in the literature concerning the developmental path of food pickiness, most researchers agree that in late childhood/beginning of adolescence, the expression of food pickiness decreases (Dovey et al., 2008; Dubois et al., 2007; Mascola et al., 2010). Parents describe non-picky eaters as children who enjoy eating, have little hesitation about eating, are nonconfrontational and cooperative about the whole mealtime process (Boquin et al., 2014). Conversely, picky eaters insist on always having the same food (Johnson et al., 2015), prepared in the same manner (Carruth et al., 1998). Otherwise, a range of behaviors such as sorting mixed foods, closely examining food, chewing for a long time, refusing to open the mouth, to vomiting if forced to swallow can be observed (Williams et al., 2005).

A neophobic rejection refers to a fearful reaction to a stimulus perceived as novel and a reaction understood as pickiness refers to the rejection of a food previously accepted because of changes in the eating situations (e.g., a different location, a different cooking process, a different presentation, a different texture, etc.). In both cases, the rejection is one response of a mismatch between the presented food and the known. The mismatch with the mental representations of the known foods may invoke feelings of uncertainty for children who may thus reject the food because it is possibly unsafe to eat. For some authors, this explains why mixed foods (which are difficult to recreate identically between servings) and fruits and vegetables (which are more prone to local or global changes between servings than other foods) are the privileged targets of food rejection (Brown & Harris, 2012; Carruth et al., 1998; Cashdan, 1998; Jacobi, et al., 2003).

1.2. Early food knowledge and categorization

Categorization failures would explain why a child might reject a food previously accepted and consequently explain why food rejection preferentially targets “familiar” fruits and vegetables, at least from the caregivers’ perspective (Brown, 2010; Dovey et al., 2008). When confronted with a known food, adults and children can rely on their concept of the food’s category to recognized it and infer its properties. For example, my concept of a tomato is of a food, precisely a vegetable, that is round, red, cultivated during summer, edible, sweet, and goes deliciously with mozzarella for an appetizer. With my concept of tomato, if I were to encounter an object that looks like a tomato, tastes like a tomato, is served with mozzarella during a hot summer, I could infer that this object is certainly a tomato. When we encounter a new instance of an object, concepts avoid us the need to examine and learn about this object (or situation) *anew* (Murphy, 2002). Furthermore, concepts enable us to take advantage of our past experiences and to generalize our knowledge to new instances or new situations. Take the previous example, if I were to encounter a new instance of a tomato, I would be able to infer its properties (e.g., that it is edible, sweet, and can be eaten raw or cooked) from my knowledge of the tomato category.

Research has identified several kinds of categories we have for the same food, each allowing inferences of different information (Nguyen & Murphy, 2003). The present dissertation focused on taxonomic (e.g., vegetables; Rioux et al., 2016) and thematic (e.g., foods served together; Thibaut et al., 2016) categories because of the respective inferences they allow, differently central to decisions we make about food. Then, early knowledge of food properties is summarized.

1.2.1. Taxonomic categories

Taxonomic categories are based on common properties shared by the members of the category. For instance, tomatoes are in the same category because they grow on plants, are sweet, contain vitamins, etc. An important characteristic of taxonomic categories is that they are organized into hierarchies of increasingly inclusive categories (Rosch, 1973); such as costoluto genovese-tomato-vegetable-food, where costoluto genovese are a kind of tomato, which are a kind of vegetable, which are a kind of food. According to Rosch (1973), from a psychological standpoint, this hierarchy is based on three levels of categorization, the most important, salient one, being the basic level of categorization (e.g., tomato, apple). Basic level is the reference level because people first identify entities at this level ("this is a chair"). Psychologically, its strength would result from the fact it is a good compromise between homogeneity and distinctivity (see Murphy, 2002; Rosch & Lloyd, 1978; Thibaut, 1999, among many others) Categories lower in the hierarchy are subordinate categories (e.g., costoluto genovese, golden apple). Categories higher in the hierarchy are superordinate categories (e.g., vegetables, fruits). Any property true for the basic level is also true for its subordinate categories (e.g., if all tomatoes have vitamins, then all costoluto genovese have vitamins as well). Developing taxonomic understanding is crucial for making inferences of internal and biochemical properties. For instance, even children know that for energy it is helpful to eat food categories that contain vitamins, such as fruits and vegetables (e.g., Thibaut et al., 2020).

Evidence suggests that, in the food domain, specific taxonomic distinctions at the superordinate level emerge around two years of age. Using a sequential touching procedure and a forced sorting task, Brown (2010) found that before 20 months, infants fail to discriminate between food and animal categories. However, after 22 months, infants are able to discriminate between food and animal categories (Brown, 2010) and systematically sort food from toy items after 30 months (Bovet et al., 2005). Additionally, Lafraire et al. (2016b) observed that 3- and 4-year-old children can discriminate foods from nonfoods matched on color and shape (e.g., a red tomato and a red Christmas ball), with significant improvements within this two-year age range. Other studies show that although 3-year-old children have somewhat accurate concepts of fruits and vegetables, there is a steep increase in the development of superordinate taxonomic knowledge between 3 and 6 years of age (e.g., Rioux et al., 2016).

1.2.2. Thematic categories

Thematically related objects are categorized together because they play complementary roles and often co-occur in time and space (Estes et al., 2011; Gelman & Markman, 1986; Golonka & Estes, 2009; Lin & Murphy, 2001). Thematic categories display various types of associations, such as temporal (e.g., morchellas served as the main dish comes before the dessert), spatial (e.g., often found together in the same dish such as tomatoes and mozzarella), productive (e.g., milk and cheese), functional (e.g., steak and knife), or possessive (e.g., the wedding cake and newlyweds). In any case, the objects play complementary thematic roles (Estes et al., 2011), a morchella is an object that one eats and a fork is an instrument used to feed oneself; the main dish and the dessert serve a different purpose but are both parts of a full meal. Thematic categories are useful in that they provide us with situational cues and inferences on the origin, use, and possible consequences of objects, which is essential to adapt to the environment. For example, knowing the thematic association of a caquelon and cheese allows us to infer that when we enter a restaurant and see that there are caquelons on every table, this restaurant is likely to be a fondue restaurant, and thus should be avoided by persons intolerant to lactose.

Regarding the development of thematic understanding in the food domain, evidence suggests that thematic categories emerge in parallel with the taxonomic categories, even creating some confusion for children. For instance, Pickard et al. (2021a) showed that 3 years of age children had above-chance performance when categorizing foods thematically (e.g., associating a burger bun with a patty). However, only from 5 years of age, children are capable of extending psychological and biological properties to taxonomic over thematic food categories (Thibaut et al., 2016).

1.2.3. Early knowledge of food properties

As evidenced, developing a rich conceptual knowledge of foods is necessary for making inference-based decisions (i.e., to predict the consequences of consumption such as growth, illness, organ functioning, etc.). In the following section, we summarize children's knowledge about food health-related properties.

Former studies revealed adults' tendency to sort foods and food properties as positive (healthy) or negative (unhealthy) for health (Rozin et al., 1996). Recent research has shown that children as young as 3 years of age already understand this distinction (Nguyen & Murphy, 2003; Nguyen, 2007) and use it productively to make inferences about the human body (Nguyen, 2008). They can accurately distinguish between healthy and unhealthy foods and provide explanations as to why a specific food has positive (e.g., "makes you strong") or negative properties (e.g., "you get sick"; Nguyen, 2007). When reasoning about the health consequences of food consumption, children can disregard other conceptual relationships in favor of an evaluative criterion. For instance, Nguyen (2008) showed that by 4 years of age, children can disregard taxonomic relationships in favor of evaluative categories (i.e., healthy and unhealthy). In Nguyen (2008), children were told that a healthy food (such as milk) "makes a body 'daxy'." Then, children were asked which of two alternative foods, one healthy (e.g., apple) and one unhealthy (e.g., potato chip), would also make a body "daxy." Results revealed that children were able to extend the property taught for a healthy food to another healthy food (i.e., from milk to apple) even when it belonged to another taxonomic category (e.g., as in milk to apple, healthy foods may include particular fruits, beverages, and so on). With evaluative primes (e.g., line drawing of a smiling face), children systematically disregarded stronger taxonomical relationships in favor of non-taxonomically-related evaluative choices (Nguyen, 2020). Furthermore, when the evaluative criterion is made central with a positive or a negative prime, children spontaneously sort foods with positive properties from foods with negative properties (DeJesus et al., 2020).

In summary, adults and children can rely on their taxonomic and thematic knowledge to recognize and understand their food environment. They can infer different kinds of information such as knowing that if they had to eat from a caquelon, cheese will be served, which, like other milk-based products, may contain lactose that they might be unable to digest and thus can make them sick. Nevertheless, such cognitive accomplishments take time to develop. Children begin to develop the abilities to make specific distinctions between superordinate categories of the food domain (e.g., vegetables and fruits) from 2 years of age, roughly when food rejection starts manifesting, to some extent, in most typically developing children.

1.3. Food rejection and the Knowledge Gaps Hypothesis

For some authors, the concomitance between the apparition of food rejection at the same period of rapid changes and improvements in children's categorization abilities is not a sheer coincidence (Harris, 2018; Lafraire et al., 2016a; Rioux et al., 2016). Children may start interpreting their food environment taxonomically and thematically between 2 and 3 years of age, however, by the end of the preschool years, they have yet to acquire the sophisticated conceptual knowledge of adults. With an underdeveloped knowledge of foods, many potential food sources appear novel and the distinction between categories may be blurry, making precise recognition difficult. For example, I did not dare pick unknown mushrooms or even mushrooms that were edible morchellas, but because they were blond I suspected them to be from another category, potentially poisonous (being ignorant that morchellas could come in other colors than black). Along this line or reasoning, some authors have proposed the Knowledge Gaps Hypothesis to interpret food rejection (Lafraire et al., 2016a; Rioux et al., 2016). Accordingly, it has been proposed that food rejection is related to impoverished conceptual knowledge.

This proposition recently received empirical support. In their series of pivotal studies, Rioux et al. (2016; 2017a; 2018a; 2018b) found a negative correlation between food rejection and food category-based abilities (e.g., categorization and inductive performance). In their first study, Rioux et al. (2016) tested 118 2- to 6-year-old children in a forced-choice task in which they had to discriminate between two superordinate categories, vegetables and fruits (Rioux et al., 2016). Higher levels of food rejection predicted lower performance on the task (see also Rioux et al., 2018a for similar results on taxonomic forced sorting tasks). Strikingly, Rioux and colleagues (2016) found that neophobic and picky children performed the same as younger children, and conversely, that neophilic and non-picky children performed just as well as older children. In later studies, Rioux et al., (2017a; 2018b) revealed that food rejection and taxonomic category-based induction performance were significantly negatively correlated. Whilst the more neophilic and less picky children referred to category membership when generalizing blank properties (e.g., "contains zuline") of a given food to another food (e.g., from a green zucchini to an orange carrot), the more neophobic and pickier children tended to generalize properties based on color similarity (e.g., from a green zucchini to a green banana; Rioux et al., 2017b). The negative relationship between food rejection and categorization abilities is not restricted to taxonomic categories but also extends to thematic categories (Pickard et al., 2021a). Using a proportional analogy task (A:B::C:?; see also Thibaut et al., 2010 for a similar paradigm), Pickard et al. (2021a) observed that when presented with a thematic food base pair (A:B; ice cream:wafer cone) the more neophobic and pickier children failed more often to correctly extend this relation to the thematic match of the target C (C:?; burger:burger bun or chicken) than their more neophilic and less picky counterparts. Intriguingly, several studies have found food neophobia to be a stronger predictor of children's food categorization abilities than pickiness (Pickard et al., 2021b; Rioux et al., 2018b). For instance, Rioux et al. (2018b) reported that food neophobia, but not pickiness, predicted (incorrect) perceptual rather than taxonomical inferences.

1.4. Conclusion

The two strongest psychological barriers to increase children's dietary variety and healthier eating behaviors seem to be food neophobia (defined as the reluctance to eat or even try foods that appear novel; Pliner & Hobden, 1992) and pickiness (defined as the rejection of a substantial number of familiar foods; Taylor et al., 2015). Food neophobia and pickiness have recently been associated with a lack of knowledge about foods (Dovey et al., 2008; Harris, 2018; Lafraire et al., 2016a; Rioux et al., 2016). Conceptual knowledge allows recognition (e.g., this is a "morchella"), categorization, and inference-based decision-making (Murphy, 2002). If children lack the appropriate conceptual knowledge, they may fail to recognize a given food. Thus, in this uncertain situation, they might avoid eating it. The avoidance, in its most severe manifestations (e.g., disruptive meal behaviors), may discourage caregivers from exposing children to previously rejected or novel foods. However, the lack of exposure may, in turn, prevent children to develop their conceptual knowledge about different food categories. Impoverished knowledge due to insufficient experiences or learning opportunities increases the subsequent likelihood that a food is not recognized and thus rejected, perpetuating the vicious circle (Figure 3; Rioux et al., 2016; 2017a).

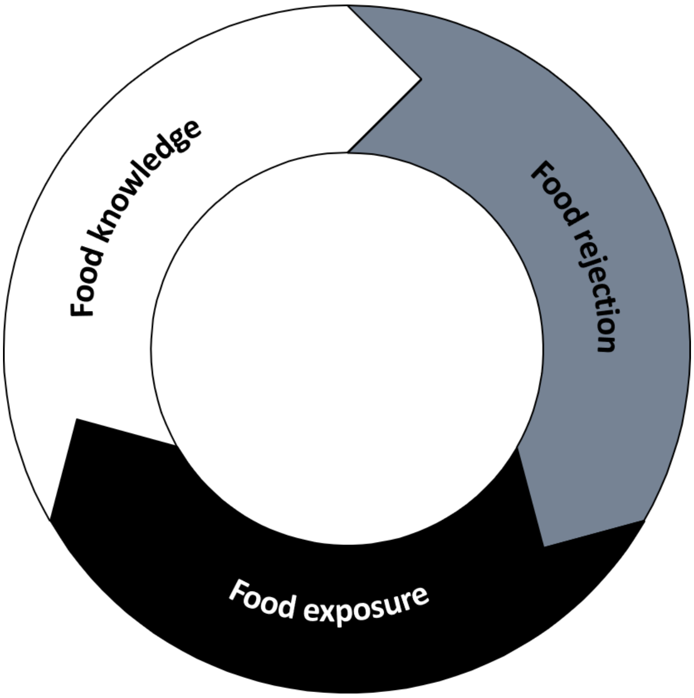

Figure 3. The vicious circle of food knowledge, food rejection, and food exposure

Chapter 2. How to break the vicious circle?

2.1. Food rejection and exposure

The mutual influence of food rejection and conceptual development in young children seems cyclical. Impoverished conceptual knowledge may increase the likelihood of food rejection. Food rejection may decrease the opportunities to learn about foods. Insufficient experience with foods may limit the development of knowledge and familiarity, thus perpetuating the circle (Rioux et al., 2016; 2017a).

2.1.1. Exposure to overcome food rejection

Conceptual knowledge development depends on former experiences and interactions with the environment (Chi et al., 1989; Fisher et al., 2015; Gelman & Markman, 1987). Increasing the level of experience an individual has with any stimulus, such as food, eases and makes subsequent categorizations of this stimulus faster (Bornstein & D'Agostino, 1994). Further, Lafraire et al. (2016a) suggested that increased experience also facilitates subsequent categorization for other members of the stimulus category. For example, through repeated mushroom picking I developed the necessary knowledge not only to correctly recognize an instance of mushroom but also other members of its category despite slight variations in shape and color.

Therefore, it has been suggested that through repeated exposure and familiarization, food rejection could be overcome (Birch & Marlin, 1982). A considerable body of research has therefore investigated whether repeated exposure to fruits and vegetables might enhance children's acceptance and reduce rejection (for reviews see Cooke, 2007; Keller, 2014). There is substantial evidence for the success of such interventions, in controlled (Birch et al., 1987; Birch & Marlin, 1982) and ecological settings like school or home environments (Mustonen & Tuorila, 2010; Park & Cho, 2015). However, if these interventions often lead to increased subsequent acceptance of the targeted food, the effects may not be enduring over long periods of time (Appleton et al., 2016; Corsini et al., 2013). Furthermore, for preschool-aged children, studies suggest that 8 to 15 exposures may be needed to changes attitudes towards an exposed food (L. Cooke, 2007; Wardle et al., 2003). This is a number greater than most parents are willing to provide (Carruth et al., 2004).

2.1.2. Food rejection to overcome exposure

It has also been pointed out that exposure interventions may not be efficient for highly neophobic and picky children (Rioux et al., 2018a; Wild et al., 2017; Zeinstra et al., 2017). Up to twenty-seven exposures can be necessary before these children accept to taste a targeted food (Williams et al., 2008). Rioux and colleagues' study (2018a) showed that in situations of increased uncertainty (i.e., exposure to atypically colored vegetables), neophobic and picky children ate significantly less exposed foods, as compared to their more neophilic and less picky counterparts.

Such interventions are confrontational in nature. They present, often novel or atypical, fruits and vegetables before asking children to eat them. However, for neophobic and picky children, such situations may trigger a strong emotional response (Mcfarlane & Pliner, 1997; Pelchat & Pliner, 1995). Indeed, food rejection has been associated with higher levels of negative emotionality (Haycraft et al., 2011), shyness (Bellows et al., 2013), and anxiety (Maratos & Sharpe, 2018). Other studies have revealed an association between food rejection and tactile defensiveness (i.e., withdrawal responses to tactile stimuli or overreactions to the experiences of touch; Smith et al., 2005). Greater levels of food rejection have also been associated with lower levels of sensation-seeking (i.e., levels in the strength of stimulation to reach the appropriate level of awakening; Galloway et al., 2003) and approach tendencies to novelty (i.e., children who are low in approach tend to show negative affect toward novel stimuli and withdraw from them; Moding & Stifter, 2016). Therefore, for neophobic and picky children, exposure interventions may not be suitable because they are too confrontational and invoke an overwhelming emotional response.

2.2. Reducing children's uncertainty: cues of food processing

Finally, for children with high food rejection exposure interventions may not be efficient. Caregivers may be discouraged from exposing children to novel foods. However, as evidenced in Chapter 1, building knowledge about foods is necessary for promoting food acceptance in children. Therefore, it is important to identify whether it is possible to reduce children's uncertainty toward a food so that exposures appear less confrontational. The current section hypothesizes that cues of food processing can reduce children's uncertainty about foods.

According to recent evidence, food processing is a visual cue that can reduce uncertainty about edibility and thus promote feelings of safety in the food domain (Coricelli et al., 2019; Foroni et al., 2013, 2016; Rioux & Wertz, 2021). Contrary to unprocessed food that is natural food with no signs of human intervention, processed food is defined as food that exhibits signs of human interventions (e.g., cooked, sliced). Evidence suggests that food processing is a relevant visual dimension that cues safety. For instance, Foroni et al. (2013) showed that adults rated unprocessed foods as less immediately edible than processed foods, which were, in turn, perceived as ready to be consumed. They also found pictures of processed foods more appealing than pictures of unprocessed foods, even when caloric content was equalized (Foroni et al., 2016). Furthermore, adults categorized processed foods as foods faster than unprocessed foods (Coricelli et al., 2019). These results suggest that adults use food processing as an edibility cue. Children also understand that processed foods are the outcome of a purposeful transformation (Girgis & Nguyen, 2020). This distinction between unprocessed and processed foods has been found to influence children's inductive strategies. For instance, Lafraire et al., (2020) showed that children did not generalize properties in the same way to processed than to unprocessed new foods. The authors contrasted three states of food processing: whole, sliced, and pureed. They observed that children's generalization patterns were different when the foods were whole as compared to processed. They suggested that children might interpret food processing as a social cue to edibility. Indeed, starting during the weaning period, solid food pieces are gradually introduced from fine pureed to sliced child-size bites to ensure minimal risk after ingestion (e.g., suffocation). Corroborating this suggestion, evidence suggests that even infants perceive cues of food processing as signaling food safety. Rioux and Wertz (2021) measured 7-to-15-month-old infants' social looking time towards adults (a strategy employed by infants who seek out social information when confronted with potential harmful stimuli) towards whole and sliced plant foods. The authors reported that infants engaged in significantly less social looking before touching the processed plant foods and sometimes, they even put these foods in their mouths, which they never did with the whole plant foods. The findings reviewed above suggest that the contribution of the level of processing dimension in the food domain is to reduce uncertainty about edibility. Interestingly, infants who displayed a higher behavioral approach of sliced fruits and vegetables were more likely to exhibit lower food rejection a year later. Therefore, cues of food processing may reduce children's uncertainty about food which ultimately could lead to overcoming rejection.

2.3. Food neophobia and perceived uncertainty

To better understand food neophobia and to construct effective interventions for increasing the consumption of fruits and vegetables in young children, it appears necessary to investigate the twofold driver of the phenomenon: the problem of gaps in knowledge (Rioux et al., 2016), but also the withdrawal strategies when facing uncertain food situations (Moding & Stifter, 2016).

The Signal Detection Theory (SDT; Macmillan & Creelman, 2004) provides a framework for studying simultaneously both drivers of food neophobia (Crane et al., 2020). SDT characterizes how perceivers separate the "signal" from distractors, referred to as the "noise", according to two underlying psychophysics components, sensitivity and strategy. Sensitivity is a perceiver's ability to discriminate the signal from the noise. Sensitivity depends upon how well the perceiver can discriminate between stimuli, of his/her ability to apply prior knowledge. Conversely, the strategy is a perceiver's tendency, when categorization cannot be avoided, to decide that stimuli are signal or noise (Figure 4). The strategy may vary as a function of the relative costs of missing the signal (referred to as *misses*) and responding to noise as signal (referred to as *false alarms*). For example, if the perceiver is asked to decide whether stimuli are morchellas (the signal) or gyromitras (the noise), he/she might treat equivocal stimuli as gyromitras more often than as morchellas (i.e., because gyromitras can be poisonous). When a perceiver has a propensity to categorize any stimulus as noise, the strategy is described as conservative. In contrast, if he/she has the propensity to categorize any stimulus as signal the strategy is referred to as a liberal strategy. Critically, it is assumed that sensitivity and strategy are independent.

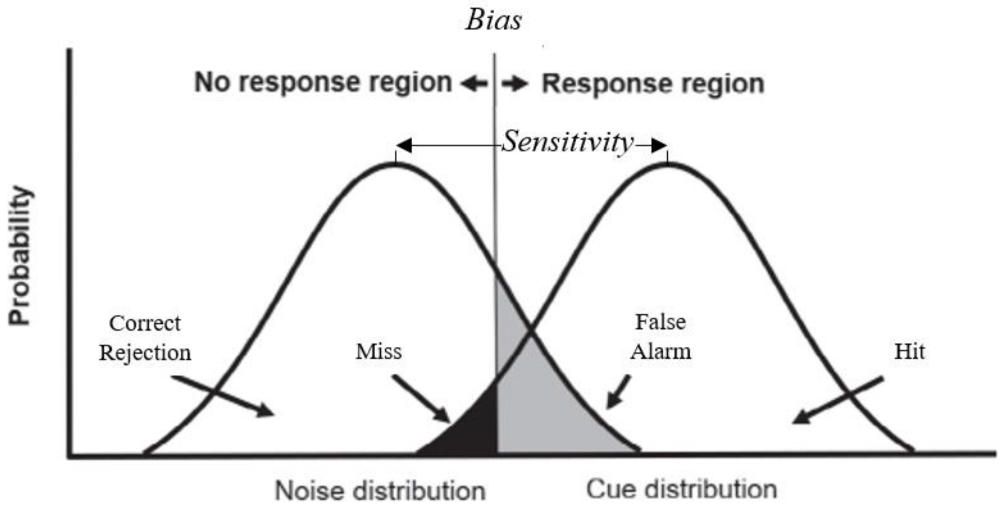

Figure 4. Graphical representation of response categories based on a bias towards the response "no"

This theoretical model allows the generation of predictions on the probability of making mistakes as a function of *perceived* uncertainty. Accordingly, an increase in uncertainty when danger is involved (e.g., consuming something inedible) leads to greater overlap between the signal and the noise, which in turn reinforces the adoption of a safer bias (Figure 5). Conversely, a decrease in perceived uncertainty should lead to "bolder" responses (e.g., to considerer most of the stimuli in the environment as safe).

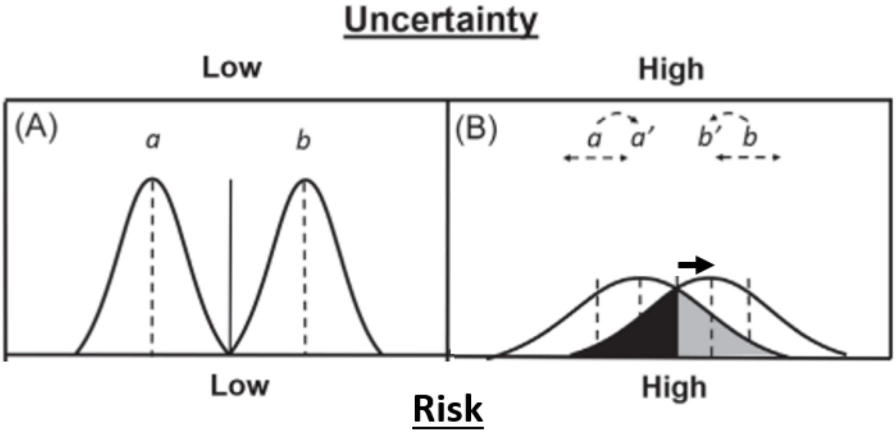

Figure 5. How perceived uncertainty and risk influence the probability of mistakes (i.e., sensitivity) and the kind of mistakes (i.e., bias) a neophobic individual can make. When the noise (*a*) and the signal (*b*) do not overlap, there are no incorrect responses (A). Uncertainty in situations of risk (B) leads to an overlap of the distributions (the center of the distribution moving from *a* to *a'* and *b* to *b*'). The increased overlap will lead a neophobic individual to increased misses (grey shading, when for example he/she has to decide whether a mushroom is a morchella or a gyromitra). Because the false alarms (black shading) are less costly, the bias (solid vertical line) should be shifted rightwards (bold black arrow; i.e., a more conservative bias). Adapted from Crane et al. (2020).

2.4. Conclusion

Repeated exposures are efficient interventions for promoting food acceptance in children (Cooke, 2007; Keller, 2014). However, their effects are limited for neophobic and picky children (De Wild et al., 2016; Rioux et al., 2018a; Zeinstra et al., 2016) who display strong emotional and physiological withdrawal reactions when presented with fruits or vegetables, particularly novel ones (Maratos & Sharpe, 2018; Moding & Stifter, 2016). Therefore, it might be necessary to first reduce their uncertainty about the targeted foods. The current chapter proposed that cues of food processing could reduce young children's perceived uncertainty about substances' edibility. Due to decreased uncertainty, children may adopt more liberal categorization strategies (Crane et al., 2020) and accept more substances as potentially edible.

Chapter 3. How to redefine the vicious circle?

3.1. Food rejection from an executive functions perspective

Food rejection can be defined in terms of category exclusivity (i.e., a presented food that derivates from representations of known foods is rejected). As described above, children with high food rejection seem to have a narrow concept of acceptable foods. In the most extreme cases, children display "brand loyalty" (Harris, 2018) and restrain themselves to a small sample of preferred foods, only accept food that comes in specific packaging, refuse a biscuit they might usually eat if it is broken or has an unusual color. Any deviation from the norm, however slight, might lead to rejection (Harris, 2018). Neophobic and picky children are also more likely to refuse mixed foods or foods for which the method of preparation might differ, such as vegetables (Brown & Harris, 2012; Carruth et al., 1998; Cashdan, 1998; Jacobi, et al., 2003).

Moving from the exclusive to the inclusive (i.e., to accept as part of a food category, foods that deviate from the known norm) is a monitoring process. Children have to be able to adapt to changes (e.g., method of preparation) and to go beyond contextual details that make a food looks unusual (e.g., the color).

Selecting appropriate behaviors and monitoring them relies on executive functions (Lyons & Zelazo, 2011; Roebers, 2017). Executive functions are defined as a set of higher-level, "supervisory", cognitive functions involved in the regulation and control of goal-directed, future-oriented behaviors (Diamond, 2013; Zelazo & Müller, 2011). Executive functions are relevant when goal-directed, non-automatic, conscious problem solving is needed in contrast with automatic forms of processing. Thus, they should contribute to adapt children or adults in uncertain situations or to modify well-learned behaviors. Executive functions are also required for children being able to identify the conceptually relevant dimensions, to ignore more salient but conceptually irrelevant dimensions, and finally, to select the appropriate conceptual representation (Andrews & Halford, 2002; Halford, 2014; Richland & Burchinal, 2013; Thibaut et al., 2010). Accordingly, executive functions development limits how many dimensions, or relationships, can be processed in parallel. They become increasingly differentiated with age (Diamond, 2013) and three separable but intercorrelated functions emerge: updating in working memory, inhibition, and cognitive flexibility (Diamond, 2013; Miyake et al., 2000; Wiebe et al., 2011).

3.1.1. Working memory

Working memory is the ability to maintain relevant information in the presence of interference (Miyake et al., 2000). This ability is, for instance, important to focus on relevant contextual dimensions (Barrett et al., 2004). Working memory has been shown to emerge as early as infancy, to increase in capacity and complexity of function from age 1 to 5 years, and to continue improving throughout childhood to adulthood (Diamond, 2013; Garon et al., 2008). Working memory is assessed, for instance, with the List Sorting task requiring children to sequence (e.g., from the smallest to the biggest, starting from foods before animals) stimuli that are presented visually and auditorily (Tulsky et al., 2014). According to Halford et al. (1998), children's ability to process multiple dimensions in parallel depends on the sophistication of working memory. Particularly, young children struggle with abstract dimensions such as category membership due to increased pressure on working memory. Instead, they tend to rely on more salient but irrelevant perceptual dimensions (DeCaro et al., 2008; Juslin et al., 2003; von Helversen et al., 2010).

3.1.2. Inhibition

Inhibition can be defined as the ability to override or interrupt undesired automatic behaviors (Logan & Cowan, 1984). This ability helps to stay focused despite distraction and to inhibit impulses. Inhibition develops in late infancy and continues to develop with age, with children improving in their ability to focus on relevant information (Davidson et al., 2006). Inhibition can be assessed with Stroop tasks (Stroop, 1935) that are used to measure interference (e.g., giving the color in which a color word is written while ignoring the color word itself). For young, preliterate children, the Real Animal Size Test (Catale & Meulemans, 2009) was developed requiring children to answer on the real size of animal pictures, either small (i.e., a butterfly and a bird) or big (i.e., an elephant and a horse). Inhibition becomes necessary in trials in which the animals are displayed with an incongruent size (e.g., a small-sized elephant or a big butterfly). It was proposed that children must first inhibit a reliance on the more salient perceptual dimensions before being able to consider other and more abstract representations (Richland et al., 2006). Some studies found that inhibition partly mediates the relationship between categorization performance and children's age (Snape & Krott, 2018; see also Rabi & Minda, 2014 who found an effect of working memory and Simms et al., 2018, and Vogelaar et al., 2021 for similar results with analogy tasks).

3.1.3. Cognitive flexibility

Cognitive flexibility can be defined as the ability to switch between perspectives or the focus of attention, flexibly adjust to changing demands or priorities (Diamond, 2013). This ability involves avoiding perseverations to old behaviors when they no longer fit a new goal (Miyake et al., 2000). Cognitive flexibility emerges early in childhood (around 4 years of age). Using the dimensional change card sort task (DCCS; Zelazo, 2006), 4-year-old children demonstrated the ability to switch accurately between two different rules (i.e., switching between answering on color or shape). The ability to reliably shift between tasks is usually thought to develop at 4 years of age and to improve later on (Diamond, 2013). Categorization, especially categorical flexibility, is related to cognitive flexibility. To test the idea that the development of categorical flexibility is not only based on conceptual knowledge but also cognitive flexibility, Blaye and Jacques (2009) tested 3-, 4-, and 5-year-old children on a flexible categorization task, in which children were requested to associate a target stimulus (e.g., a dog) with both a taxonomic associate (i.e., a snail) and a thematic associate (i.e., a kennel), while ignoring an unrelated stimulus (i.e., a phone). In this categorization task, children had to first select between two conflicting but correct choices and immediately switch to a second type of categorization. The authors observed that if the three age groups had above-chance performance to alternatively select the two correct choices, rapid change in categorical flexibility occurred between 4 and 5 years. They concluded that this period coincides well with the rapid change observed on the DCCS. Supporting this relationship between categorization abilities and performance on the DCCS, Lagarrigue and Thibaut (2020) presented preschool-aged children with two objects sharing the same label (e.g., “Dajo”) and a nonobvious dimension (i.e., the texture). Then the authors presented two new objects and asked which between a shape-match object and a texture-match object would also share the same label. Their results revealed that higher scores on the DCCS predicted the generalization of the novel label to the texture-match object. Further, more flexible children are not only better at using more abstract dimensions, but they can also generalize this behavior to new stimuli (Kharitonova et al., 2009).

In sum, the three executive functions can play a role at various levels of categorization. Working memory may help children to *keep in mind* even abstract dimensions and conceptual representations. Before being able to represent the target stimulus using another form of categorization, children may need to *inhibit* the already selected preferred or dominant form of categorization, which is irrelevant. Finally, children must *flexibly* represent the object along with other potentially relevant forms of categorization in order to select the correct conceptual representation. Categorical flexibility involves having good knowledge of different forms of categorization and executive functions. Furthermore, executive functions develop concurrently with vocabulary and there is a strong association between the two during the preschool years (Gooch et al., 2016; Weiland et al., 2014). Both executive functions and vocabulary are crucial for categorization, though the evidence is still developing on the intricacies of executive functions development.

3.2. Executive functions and monitoring influence on eating

Other reasons to refer to executive functions in the context of food behavior are obesity and anorexia nervosa. This section first reviews the evidence suggesting that severe food rejection is a potential risk factor for the development of both obesity and anorexia nervosa (i.e., a curvilinear relationship; Perry et al., 2015), before summarizing their relations with performance on executive function tasks.

3.2.1. A curvilinear relationship

To a certain extent, food pickiness and neophobia are present in most typically developing children (Moding & Stifter, 2018; Rioux et al., 2017a). However, problems arise for important food rejection behaviors leading to later problematic eating behaviors (Johnson et al., 2018). For instance, disruptive behaviors (e.g., tantrums) may discourage caregivers from introducing variety in meal preparations (Carruth et al., 1998; Johnson et al., 2018; Williams et al., 2005). However dietary variety is important for normal and healthy development. When food rejection is severe and results in reduced dietary variety it can have negative consequences on health (Nicklaus, 2009; Nyaradi et al., 2013). It has been suggested that the consequences of food rejection on health may be curvilinear (Perry et al., 2015). This means that food rejection may be related to both anorexia nervosa and obesity or overweight. Longitudinal studies of children from birth to early adulthood suggested that food rejection in childhood was a significant risk factor for the development of anorexia nervosa in adolescents (Herle et al., 2020; Kotler et al., 2001; Marchi & Cohen, 1990; Nicholls & Viner, 2009). Key evidence has recently emerged from the 1990 Avon Longitudinal Study of Parents and Children (Boyd et al., 2013) which followed 13,998 babies from birth to twenty years of age. Further analysis of this data revealed that childhood severe food rejection was associated with increased risk for anorexia nervosa compared to less severe and more transient food rejection (Herle et al., 2019). On the other hand, it has been argued that since food rejection significantly reduces the consumption of fruits and vegetables, food neophobia and pickiness may, instead, lead children to restrict themselves largely to palatable, energy-dense, high-fat, high-sugar foods, which in turn could put children at risk for excess weight gain (Carruth et al., 2004). Recent evidence from Finnish (Knaapila et al., 2015) and Italian (Proserpio et al., 2018) adults populations suggests that participants suffering from obesity were significantly more neophobic (food neophobia was measured using the Food Neophobia Scale, Pliner & Hobden, 1992) compared to a healthy control group. However, studies that have systematically examined the relationship between children's food rejection and health status are scarce and have often produced conflicting results (e.g., Brown et al., 2016; Laureati et al., 2015). Nevertheless, the impact of food rejection may extend beyond childhood (Nicklaus et al., 2005) and, therefore, it is of critical importance to investigate factors associated with food neophobia and pickiness, particularly if we wish to construct effective interventions to promote compliance to healthy eating behavior among young children.

3.2.2. Executive functions and obesity

Some studies demonstrated that obese children had impaired performance in working memory tasks from the Wide Range Assessment of Memory and Learning (Maayan et al., 2011) or such as The Digit Span Memory Task (Wu et al., 2017). However, other studies have produced null findings (Cserjési et al., 2007; Verdejo-García et al., 2010). The relationship between impaired performance in inhibition tasks and obesity has been observed in adults (for reviews see Bartholdy et al., 2016 and Lavagnino et al., 2016) and young children (Groppe & Elsner, 2015; Rollins et al., 2014). However, whereas in older groups, inhibition had been measured using Go/No-Go or Stroop tasks, many studies with preschoolers relied on questionnaires such as the Children's Behavior Questionnaire (Rothbart et al., 2001). An association between higher BMI and lower cognitive flexibility measured using tasks such as the Wisconsin Ward Sorting Test (Grant & Berg, 1948) has been found in adults (Boeka & Lokken, 2008; Cserjési et al., 2009). With children, at least three studies have demonstrated impaired performance in cognitive flexibility and obesity (Cserjési et al., 2007; Delgado-Rico et al., 2012; Verdejo-García et al., 2010). Verdejo-Garcia et al.' study (2010) is of particular interest since it revealed that cognitive flexibility (measured by the Set Shifting Trail Making Test) was the most significantly affected executive function in overweight children.

3.2.3. Executive functions and anorexia nervosa

To date, there are no indications of lower performance in working memory in anorexia nervosa (Rose et al., 2012; Seidel et al., 2021; Stedal et al., 2012). There is mixed evidence regarding the presence of inhibition difficulties in adults with anorexia nervosa, with some researchers reporting no difference (Gillberg et al., 2010) and others reporting significantly lower performance as compared to healthy control (Brewerton et al., 2009). However, no differences in inhibition abilities have been found in childhood anorexia nervosa (Rose et al., 2012; Stedal et al., 2012). Conversely, a review of 15 studies has shown that performance in cognitive flexibility is consistently found to be lower in anorexia nervosa patients than in healthy individuals (Roberts et al., 2007). Furthermore, Stedal et al. (2012) show that at 9 years of age, children with anorexia nervosa do not have specific difficulties on executive functions tasks, except cognitive flexibility. Of note, anorexia nervosa patients have been found to obtain better performance than healthy control on vocabulary tests (Stedal et al., 2012, 2013).

3.3. Conclusion

Food neophobia and pickiness can be interpreted in terms of lack of adaptability to changes. When a food or an eating situation deviates from the norm it is not accepted (Harris, 2018). Being able to accept changes and to adapt to them are skills monitored by executive functions. Further, executive functions are also important cognitive mechanisms for reasoning on the most relevant information in a given context and use knowledge appropriately (Blaye & Jacques, 2009; Lagarrigue & Thibaut, 2020). If executive functions are underdeveloped in children with high levels of food rejection, adaptability to changes and understanding of conceptual relations between foods might be hindered, resulting in poorer categorization abilities as compared to children with lower levels of food rejection.

Chapter 4. Objectives, hypotheses, and methodologies

The literature suggests a putative and cyclical relation among food rejection (i.e., food neophobia and pickiness), conceptual development, and food exposures. In an attempt to better understand the vicious circle, the present thesis investigated whether cues of food processing could reduce children's uncertainty about food edibility. Furthermore, a redefinition of the circle was attempted from an executive functions perspective. Accordingly, executive functions may play a direct or a mediator role in the relationship between food rejection and categorization abilities. These two objectives are presented successively in the present chapter. For each objective, the specific research hypotheses are detailed as well as the methods used to test them.

4.1. Food processing to reduce children's uncertainty

4.1.1. Objectives

Repeated exposures interventions have limited effects for neophobic and picky children (De Wild et al., 2016; Rioux et al., 2018a; Zeinstra et al., 2016) who display strong emotional and physiological withdrawal reactions when presented with fruits or vegetables, particularly novel ones (Maratos & Sharpe, 2018; Moding et al., 2014). Therefore, it is important to investigate how to reduce children's uncertainty about the targeted foods.

The first objective of the present thesis is to investigate whether cues of food processing could reduce young children's perceived uncertainty about substances edibility.

4.1.2. Hypotheses

Neophobic children anticipate that novel foods will have negative health consequences if consumed (Johnson et al., 2018).

Our first hypothesis is that higher levels of food neophobia predict a broader generalization of negative consequences associated with food consumption as compared with lower levels of food neophobia. However, children should generalize less the negative consequences of food consumption to foods displaying visual cues of food processing than to raw foods.

The twofold driver of food neophobia, i.e., gaps in food knowledge (Rioux et al., 2016) and withdrawal strategies from an uncertain food-related situation (Moding & Stifter, 2016), has never been investigated simultaneously. However, it appears necessary to study both drivers to better understand food neophobia and to construct effective interventions for increasing the consumption of fruits and vegetables in young children.

The second hypothesis of the present thesis is that children's food neophobia predicts their categorization performance and strategy under uncertainty about stimuli edibility. However, cues of food processing could reassure children about stimuli edibility.

4.1.3. Methodologies

In each experiment we conducted, children's levels of food rejection were collected using the Child Food Rejection Scale (CFRS; Rioux et al., 2017a). The CFRS is a hetero-evaluation questionnaire that was developed to assess 2-to-7-year-old children's food rejection on two subscales, one measuring children's food neophobia (6 items), the other measuring pickiness (5 items). On a 5-point Likert-like (*Strongly disagree, Disagree, Neither agree nor disagree, Agree*, *Strongly agree*), caregivers were asked to rate 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*").

To investigate these two hypotheses, an induction task (Chapter 5) and two categorization tasks were conducted (Chapter 6). In the induction task, a first familiar food was associated with a property. Then, children were asked whether familiar or unfamiliar foods would also manifest the positive (e.g., "gives strength") or negative property (e.g., "gives nausea) of a first familiar food. In the categorization tasks, we tested children's abilities to discriminate fruits and vegetables from nonfoods matched on color and shape (e.g., a red tomato and a red Christmas ball). In both chapters (5 & 6), we contrasted two states of stimuli: whole and sliced. We added food processing (i.e., sliced) to modulate the levels of perceived uncertainty since, according to current findings, slicing reduces children's uncertainty with respect to stimulus edibility (e.g., Coricelli et al., 2019; Rioux & Wertz, 2021).

4.2. Food rejection and categorization abilities from an executive functions perspective

4.2.1. Objectives

Food rejection can negatively predict children's categorization abilities. The lower performance witnessed in children with high food rejection has been associated with a lack of knowledge about foods (Dovey et al., 2008; Harris, 2018; Lafraire et al., 2016a; Rioux et al., 2016). However, neophobic and picky children's categorization abilities and behaviors can also be interpreted in terms of underdeveloped executive functions.

The second objective of the present thesis is to identify whether executive functions may be involved, directly, or as mediating factors in the relation between food rejection and categorization.

4.2.2. Hypotheses

Food neophobia and pickiness can be interpreted in terms of lack of adaptability to changes. When a food or an eating situation deviates from the norm it is not accepted (Harris, 2018). Being able to accept changes and to adapt to them relies on executive functions.

The third hypothesis of the present thesis is that higher levels of food rejection are associated with lower performance in executive functions.

Being able to accept changes and to adapt to them are skills monitored by executive functions. Further, executive functions are also important cognitive mechanisms predicting categorization abilities for reasoning on relevant information in a given context and use knowledge appropriately (Blaye & Jacques, 2009; Lagarrigue & Thibaut, 2020).

The fourth hypothesis of the present thesis is that higher levels of food rejection may lead to a decrease in categorization abilities through a mediating effect in executive functions (Figure 6).

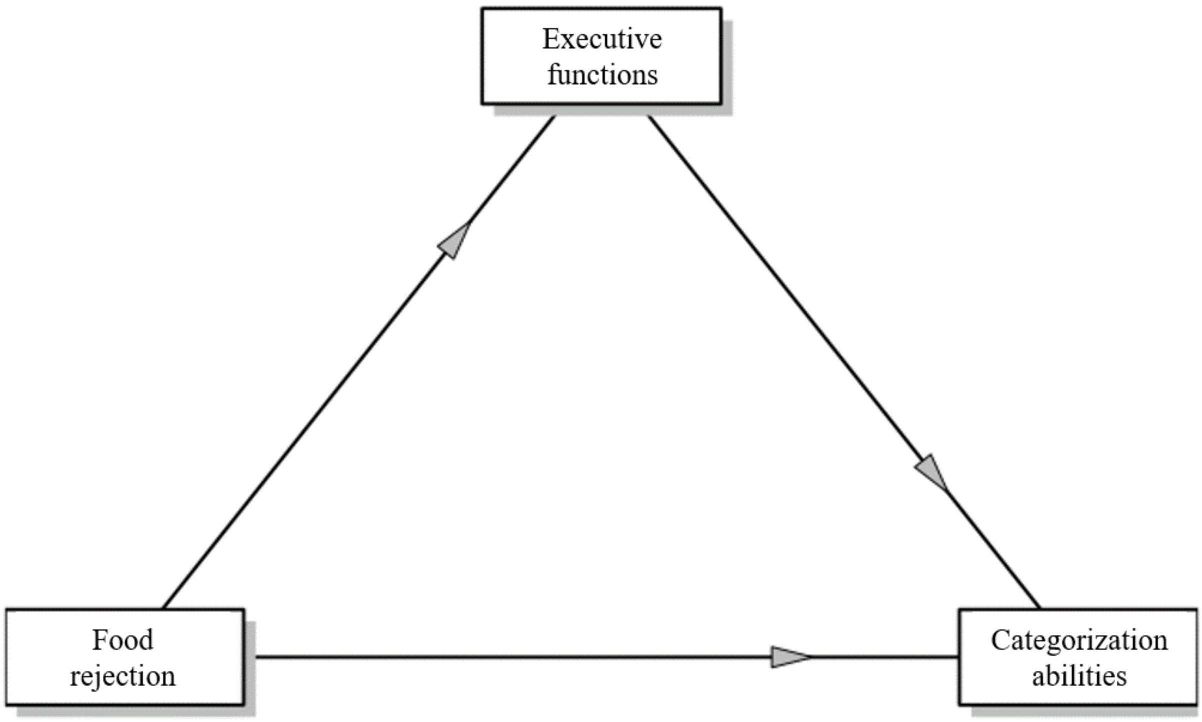

Figure 6. Executive functions as a plausible mediating effect of the relation between food rejection and categorization abilities

4.2.3. Methodologies

To investigate the first hypothesis, we conducted an experiment assessing whether children's food rejection scores would be associated with their executive functions scores and in the positive case which executive function would be associated with which food rejection, neophobia or pickiness (Chapter 7). We used executive functions tasks used for children between 3 and 6 years old. We selected the List Sorting Task (Tulsky et al., 2014), the Real Animal Size Test (Catale & Meulemans, 2009), and the Dimensional Change Card Sort (Zelazo et al., 2013), respectively testing children's working memory, inhibition, and cognitive flexibility. We also tested children on a vocabulary test (EVIP; Dunn & Dunn, 2007) taken as a proxy to world knowledge (Ashton et al., 2000) to disambiguate the relative contribution of general knowledge versus cognitive mechanisms.

To investigate the second hypothesis, we used the same battery of tests and two categorization tasks (Chapter 8). The first experiment capitalized on the initial task that observed the relation between children's food rejection and categorization abilities (Rioux et al., 2016) and extended it with measures of executive functions. The second experiment was a flexible categorization task in which children had to alternatively associate the same food with two exemplars from taxonomic and thematic categories while ignoring an unrelated food choice (adapted from Blaye and Jacques' flexible categorization task, 2009).

PART B. FOOD PROCESSING TO REDUCE CHILDREN'S UNCERTAINTY

Chapter 5. Strength or nausea? Children's reasoning about the health consequences of food consumption

This chapter presents a first experiment, designed to examine the relationship between food neophobia and strategy of responses under situations of uncertainty about stimuli edibility.

126 children, aged 3–6 years, performed an induction task in which they had to generalize positive or negative health-related properties to familiar or unfamiliar foods, whole or sliced.

The results indicated that children with high levels of food neophobia had an increased likelihood of extending negative properties to all foods regardless of whether they were unfamiliar or familiar, processed or whole.

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Strength or Nausea? Children's Reasoning About the Health Consequences of Food Consumption

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Children's reasoning on food properties and health relationships can contribute to healthier food choices. Food properties can either be positive ("gives strength") or negative ("gives nausea"). One of the main challenges in public health is to foster children's dietary variety, which contributes to a normal and healthy development. To face this challenge, it is essential to investigate how children generalize these positive and negative properties to other foods, including familiar and unfamiliar ones. In the present experiment, we hypothesized that children might rely on cues of food processing (e.g., signs of human intervention such as slicing) to convey information about item edibility. Furthermore, capitalizing on previous results showing that food rejections (i.e., food neophobia and picky eating) are a significant source of inter-individual variability to children's inferences in the food domain, we followed an individual approach. We expected that children would generalize the positive properties to familiar foods and, in contrast, that they would generalize more often the negative properties to unfamiliar foods. However, we expected that children would generalize more positive and less negative properties to unfamiliar sliced foods than to whole unfamiliar foods. Finally, we expected that children displaying higher levels of food rejections would generalize more negative properties than children displaying lower levels of food rejections. One-hundred and twenty-six children, aged 3–6 years, performed an induction task in which they had to generalize positive or negative health-related properties to familiar or unfamiliar foods, whole or sliced. We measured children's probability of generalization for positive and negative properties. The children's food rejection score was assessed on a standardized scale. Results indicated that children evaluated positively familiar foods (regardless of processing), whereas they tend to view unfamiliar food negatively. In contrast, children were at chance for processed unfamiliar foods. Furthermore, children displaying higher levels of food rejections were more likely to generalize the negative properties to all kinds of foods than children displaying lower levels of food rejections. These findings entitle us to hypothesize that knowledge-based food education programs should take into account the valence of the properties taught to children, as well as the state of processing of the food presented. Furthermore, one should take children's interindividual differences into account because they influence how the knowledge gained through these programs may be generalized.

Keywords: food familiarity, food processing, food rejection, cognition, inductive reasoning, neophobia

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INTRODUCTION

Dietary variety is needed for normal and healthy child development (Nicklaus, 2009; Nyaradi et al., 2013). However, in many Western countries, there is a lack of dietary variety due to the low consumption of fruits and vegetables (DeCosta et al., 2017). As a consequence, childhood nutrient deficiencies and obesity are becoming increasingly common (Birch and Fisher, 1998; Falciglia et al., 2000; Centers for Disease Control and Prevention, 2015; World Health Organization, 2015a,b). Nutrient deficiency is of particular concern as dietary variety may protect against long-term chronic diseases (Power and Parsons, 2000; Tucker et al., 2006; Zappalla, 2010). The rise in risk factors for diseases emphasizes the importance of understanding how children learn and reason about food and nutrition.

From a cognitive perspective, extending children's food repertoire can be seen as a generalization problem, in which children have to rely on their prior knowledge about familiar foods to extend it to other foods, either familiar or unfamiliar. Knowing that a familiar food has positive (or negative) effects on health, both children and adults can extend this information to other foods and choose foods (acceptance or rejection) accordingly. Inductive reasoning is a fundamental capacity that allows us to generalize a property from a familiar to an unfamiliar instance of a given category (see Murphy, 2002; Hayes, 2007; Gelman and Davidson, 2013, for reviews). For example, understanding that a tomato is a source of vitamins, or gives strength, could allow children to extend this property to other tomatoes (even if those tomatoes vary slightly in size, color, or shape; Murphy, 2002). Beyond other exemplars of the tomato category, children might also generalize these properties to other unfamiliar vegetables because tomato belongs to the vegetable category. To date, there is an extensive body of research demonstrating children's early abilities to reason inductively (Gelman and Markman, 1986; Welder and Graham, 2001; Gelman, 2003; Sloutsky and Fisher, 2004a,b).

The present paper's aim is to focus on children's inductive reasoning (i.e., generalization) of health-related food properties that were either positive/beneficial (e.g., "gives strength") or negative/detrimental (e.g., "results in nausea"). More precisely, the present study explored conditions under which children would generalize both types of properties from familiar foods to other familiar and unfamiliar foods belonging to the same taxonomic categories (e.g., vegetable). We focused on vegetables and fruits as it has been reported that children are less willing to try novel instances of these categories compared to other kinds of foods (Dovey et al., 2008). We also contrasted two types of food presentations, raw (whole) vs. processed (sliced) to test the idea that food transformation might act as a cue for food quality/safety in children (Foroni et al., 2013; Coricelli et al., 2019; Lafraire et al., 2020). Indeed, evidence suggests that children are sensitive to unfamiliar perceptual features to generalize food edibility (Rioux et al., 2018a). Therefore, for unfamiliar foods their processing states might convey the information that they have been prepared to be eaten and, thus, are edible. Therefore, the types of food presentations could influence the way children reason about foods and their properties. We also addressed these questions from an individual difference perspective by exploring the possible role of food rejection dispositions in children's induction within the domain of food categories. Indeed, recent studies have reported a relationship between inductive reasoning and the intensity of food neophobia and pickiness in preschoolers (Rioux et al., 2018a,b).

Generalization inferences with meaningful properties critically depend on determining which known characteristics of the categories are causally related to or predictive of the property to be generalized (Heit and Rubinstein, 1994; Hayes and Lim, 2013; Bright and Feeney, 2014; Hayes and Heit, 2018). For instance, children use taxonomic food categories to make inferences about biological properties (i.e., generalizing biological properties to other foods in the same taxonomic category) but use script food categories to make inferences about contexts or situations (such as milk and cereals as breakfast foods) in which foods are usually eaten (Nguyen, 2012; Thibaut et al., 2016). Children can also attend to external information (a category based on a value-laden assessment such as "healthy" or "unhealthy") to make inferences about the effects of eating (Nguyen, 2008). Therefore, children can selectively and productively cross-generalize the properties of familiar foods based on the appropriate knowledge required. In the case of foods children are unfamiliar with, recent evidence reveals that children attend to the perceptual features of these foods to guide their inductions (Rioux et al., 2018b; Lafraire et al., 2020). In the present study, familiar and unfamiliar foods have been compared to isolate the characteristics perceived as central by children when they have to generalize positive or negative food properties. Among these characteristics, we hypothesized that the perceived level of food processing could guide children's inductions of positive and negative properties to unfamiliar food stimuli.

Food processing is a unique and universal behavior aiming at increasing food eatability and edibility (Carmody et al., 2011; Wrangham, 2013; Zink and Lieberman, 2016). Adults interpret food processing features as edibility cues. For example, Foroni et al. (2013) showed that participants rated non-processed foods as less immediately edible than processed foods, which were perceived as ready to be consumed. Processed foods were also categorized as food quicker than non-processed foods (Coricelli et al., 2019). Thus, adults seem to use transformation features as edibility cues. Children also understand that processed foods are the outcome of a purposeful transformation (Girgis and Nguyen, 2020). This distinction between unprocessed and processed foods also influences children's inductive strategies. For instance, Lafraire et al. (2020) showed that children did not generalize properties in the same way to processed and raw unfamiliar foods. The authors contrasted three states of food processing: whole, sliced, and pureed. They observed that children's generalization patterns were different when the foods were raw (whole) as compared to processed. They suggested that children might interpret food processing as a social cue to edibility. Indeed, starting during the weaning period, solid food pieces are gradually introduced from fine pureed to sliced child-size bites to ensure minimal risk for ingestion. Despite the fact that slicing is a simple type of food processing (compared to the culinary transformation manipulated by Foroni et al., 2013; Coricelli et al., 2019), children nevertheless favor raw sliced fruits and vegetables over raw unprocessed alternatives (Swanson, et al., 2009; Olsen, et al., 2012; Baker et al., 2015). Furthermore, cutting and slicing are often the starting point of more elaborated food preparation processes. However, whether or not children would use slicing as a cue associated with food safety remains an entirely open issue.

Former studies revealed adults' tendency to sort foods and food properties as positive or negative for health (Rozin et al., 1996). Recent research has shown that children as young as 3 years of age already understand this distinction (Nguyen and Murphy, 2003; Nguyen, 2007) and use it productively to make inferences about the human body (Nguyen, 2008). They can accurately distinguish between healthy and unhealthy foods, and provide explanations as to why a specific food has positive (e.g., "makes you strong") or negative properties (e.g., "you get sick"; Nguyen, 2007). When reasoning on health consequences of food consumption, children can disregard other categorical relationships in favor of an evaluative criterion. For instance, in a related issue, Nguyen (2008) showed that by the age of 4, children can disregard taxonomic relationships in favor of evaluative categories (i.e., healthy and unhealthy). In Nguyen (2008), children were told that a healthy food (such as milk) "makes a body 'daxy'." Then, children were asked which of two alternative foods, one healthy (e.g., apple) and one unhealthy (e.g., potato chip), would also make a body "daxy." Results revealed that children were able to extend the property taught for a healthy food to another healthy food (i.e., from milk to apple), even when it belonged to another taxonomic/script category (e.g., healthy foods may include particular fruits, beverages, and so on). Actually, with evaluative primes (e.g., line drawing of a smiling face), children systematically disregard stronger taxonomical relationships (e.g., between two foods) in favor of a non-taxonomically-related evaluative choice (e.g., an animal; Nguyen, 2020). Furthermore, when the evaluative criterion is made central with a positive or a negative prime, children spontaneously sort foods with positive properties from foods with negative properties (DeJesus et al., 2020). However, to the best of our knowledge, no study has investigated how children generalize health-related properties from a familiar food to other foods (both familiar and unfamiliar foods).

For familiar foods, adults and children can rely on their background knowledge (Aldridge et al., 2009). For instance, 3-to-4-year-old children tend to associate familiar fruits and vegetables such as apples or spinach with positive bodily effects (Nguyen, 2007; Thibaut et al., 2020). On the contrary, children are uncomfortable eating food when they cannot anticipate the consequences of their ingestion (Pliner and Hobden, 1992) since unfamiliar substances might be toxic. According to Rozin (1979), food neophobia is an adaptive strategy for children to avoid the risk of ingesting new (and potentially poisonous) items. More precisely, food neophobia is defined as the reluctance to eat, or the fear of, new foods (Pliner and Hobden, 1992). It is now well-established that a proportion of 3-year-old children and beyond exhibit food neophobia and pickiness (i.e., the two main dimensions of food rejection dispositions, see Dovey et al., 2008; Lafraire et al., 2016, for reviews). Interestingly, the intensity of food rejections represents a significant source of inter-individual variability with respect to children's inferences in the food domain (Rioux et al., 2018a,b). Rioux et al. (2017) have demonstrated that children with high rejection scores on a relevant scale, tended to have poorer categorization and induction performances compared to children with lower scores on the same scale. For example, Rioux et al. (2018b) showed, in a property induction task, that children with higher food rejection scores rely on superficial color-similarity to drive their inductive strategies, whereas children with lower food rejections scores rely on category membership. However, to date, no studies have investigated the influence of food rejections on the generalization of health-related food properties. Potential differences between high and low rejection children regarding health issues as a function of familiarity is an important issue, since food rejection is associated with low consumption of fruit and vegetables (Dovey et al., 2008) and with a less diverse diet (Birch and Fisher, 1998; Falciglia et al., 2000). Therefore, investigating neophobic and picky children's reasoning on food properties for inferences about the negative health-related effects of eating is of both theoretical and practical importance. Indeed, if these children are more sensitive to food's risks, they might generalize this information to more foods than their neophobic, or less fussy, counterparts.

In this paper, we assessed children's reasoning on the positive-negative distinction and its interaction with individual differences in food rejections. Most of the previous studies focused on children's inductive reasoning on foods with familiar or unfamiliar foods and did not directly compare them. In addition, they did not manipulate food processing states (whole, sliced, or cooked), which has been shown to influence edibility judgments and food preferences, at least in adults. Here, we will compare food familiarity and food processing states and their interaction with food rejection tendencies. More precisely, we asked children to generalize a positive or negative property associated with a training familiar fruit or vegetable, to other foods from the same taxonomic category as the training, familiar or unfamiliar, and whole or sliced.

H1. We expect that children would generalize more positive than negative properties to familiar foods compared to unfamiliar foods. The reason is that other familiar healthy foods are known to be safe. A related hypothesis is that children should generalize less positive properties and more negative properties to unfamiliar foods because they are more cautious about unfamiliar foods.

H2. If food processing acts as a cue for food safety/quality, children will generalize more positive than negative properties to sliced than to whole unfamiliar foods.

H3. Food neophobia is defined as the fear of novel foods. We thus expect that neophobic children will generalize more negative properties to unfamiliar foods compared to their neophilic counterparts.

MATERIALS AND METHODS

Participants

Participants were 126 children (60 girls and 66 boys; age range = 3.44–6.42 years; mean age = 5.30 years; *SD* = 0.714). They were preschoolers from eastern France predominantly Caucasian and came from middle-class urban areas. Informed consent was obtained from their school and their parents. The procedure was in accordance with the Declaration of Helsinki and followed institutional ethics board guidelines for research on humans. This study was reviewed and approved by an official agreement between the Academia Inspection of the French National Education Ministry and the University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Materials

In order to assess each child's food rejection dispositions, caregivers filled out the Child Food Rejection Scale (CFRS; Rioux et al., 2017). The CFRS was developed to assess, by hetero-evaluation, 2-to-7-year-old children's food rejection on two subscales: one is measuring children's food neophobia (six items) and one is measuring their pickiness (five items). On a 5-point Likert-like (*Strongly disagree*, *Disagree*, *Neither agree nor disagree*, *Agree*, and *Strongly agree*), caregivers were asked to rate 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*"). Each answer was then numerically coded with high scores indicating higher food neophobia and pickiness (scores could range from 6 to 30 for neophobia, mean = 16.2, *SD* = 4.89; from 5 to 25 for pickiness, mean = 16.6, *SD* = 3.84; and global food rejections from 11 to 55, mean = 32.8, *SD* = 7.70).

We constructed four biological properties that a food was said to have for a fictional character called "Feppy." The properties were chosen so that they could be understood by young children (see Thibaut et al., 2016 for other examples). There were two positive and two negative properties. Pictures depicting "Feppy" going through the four properties related changes caused by food ingestion were generated (see **Figure 1**). We provided these pictures to help children interpreting the properties. Since food neophobia is mainly targeting vegetables and fruits (Dovey et al., 2008), we chose the stimuli in these categories. We constructed four sets of stimuli (n = 36), two sets made up of vegetables (n = 18, 2 training pictures + 16 test pictures), and the two sets made up of fruits (n = 18, 2 training pictures + 16 test pictures). Each set was composed of a familiar training and eight test food items, that is, four familiar and four unfamiliar stimuli. Moreover, in order to avoid that children would generalize on the basis of taxonomic categories (i.e., fruits or vegetables) when reasoning about the properties, each experimental set was homogeneous (e.g., only fruits or only vegetables).

We selected slicing, with sharp edges to not look accidental (like crushing), because slicing is a common food transformation and also, in the case of familiar foods, does not make the food unrecognizable. Transformations such as crushing or puree most often result in something which is no longer recognizable. Trainings and tests were evenly divided into whole and sliced.

For familiar stimuli, we first selected 48 common foods that are often served in school canteens, from a variety of internet sites and picture databases (e.g., FoodCast database; Foroni et al., 2013). Since food processing of a familiar food item might impact its recognizability and familiarity which, in turn, may impact induction, all familiar foods were controlled for recognition prior to the study by 12 3-to-7-year-old children using a picture identification task. None of these children participated in the actual study. Stimuli pictures that were not successfully named by at least 70% of the children were removed from the final set.

Secondly, to generate the unfamiliar subset of pictures, 95 adults rated 25 *a priori* unfamiliar foods on a 7-point Likert-like scale (ranging from *Not familiar at all* to *Very familiar*). Following common practice (Rioux et al., 2018a,b,c; Lafraire et al., 2020), we assumed that children would not know foods that would be unknown to most adults. Pictures for which the rating was beyond 2.5 (out of 7) were removed.

To avoid any similarity confound in a food pair between trainings (e.g., sliced orange) and tests (e.g., a whole banana, whole Buddha fingers, a sliced star fruit, or a sliced strawberry), in each set, we selected training items that were dissimilar to the tests of their set in shape, type of slicing (e.g., chopped in cubes, quarters, or slices), and color (see **Figure 2** for a set of stimuli used in the property generalization task). An online test was conducted to control for global perceptual similarity. Eighty adults were instructed to assess the similarity between trainings and tests on a 7-point Likert-like scale (ranging from *Not similar at all* to *Extremely similar*). Participants were presented with 32 food pairs, eight Whole-Whole pairs, eight Whole-Sliced pairs, eight Sliced-Whole pairs, and eight Sliced-Sliced pairs. The presentation order of the pairs was fully randomized across participants. **Table 1** provides the perceptual similarity ratings. They were significantly below 4 (out of 7, i.e., neither similar nor dissimilar) for each food pair type. This control was important to avoid as much as possible any color or shape similarities between training and test pictures of a set because these similarities have an impact on children's performances of food category-based induction tasks (Rioux et al., 2018a,b).

TABLE 1 | Similarity rating for each food pair type.

Food pair type	Mean	*SD*
Whole-Whole	2.56^{***}	1.05
Whole-Sliced	2.26^{***}	1.04
Sliced-Whole	2.24^{***}	1.00
Sliced-Sliced	3.21^{***}	1.13

Wilcoxon tests compared food pair type similarity ratings against 4. $^{***}p < 0.001$.

Design

Children participated in a within-subject design where health-property Valence (Positive and Negative), Training State (Whole familiar and Sliced familiar), and Test (Whole familiar, Sliced familiar, Whole unfamiliar, and Sliced unfamiliar) were crossed (see **Table 2**).

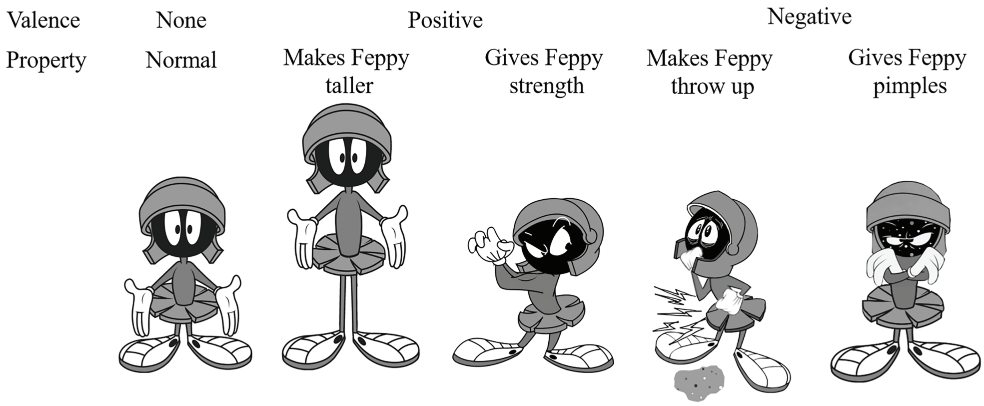

FIGURE 1 | Pictures of Feppy used in the property generalization task.

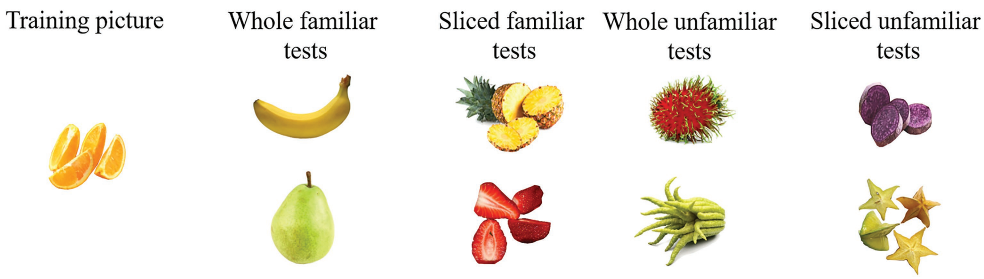

FIGURE 2 | Example of a set of fruit stimuli used in the property generalization task.

Procedure

Children were tested individually in a quiet room at their school. The experiment consisted of two parts run successively and in a constant order for all the children.

Induction Task

Children sat at a table with two mailboxes. The experimenter told the children that they would play a game and, then, showed two images of Feppy, each on top of one of the mailboxes. One image displayed Feppy in a neutral condition (i.e., neither in a positive or negative condition). The other image of Feppy illustrated the targeted verbal property (e.g., "Feppy is throwing up," see **Figure 1**). For each set (e.g., Set #3; **Table 2**), children learned that a stimulus (e.g., a sliced orange), displayed on the training picture, and had an effect on Feppy after he ate it (e.g., "Makes Feppy throw up"). Then, they were asked whether the eight test pictures would also have the same effect on Feppy if he ingested them. Opaque mailboxes were used to prevent children from comparing each test item with the others, which might influence their answer (see Thibaut and Witt, 2015, for a discussion of conceptual comparison strategies). In contrast, the training items were kept in view during the entire experiment (see **Figure 3**). For each set, the instructions were as follows (translated from French): "This is Feppy (pointing to Feppy in a neutral condition). Doctors who observed Feppy discovered how his body could be affected by what he eats.

TABLE 2 | Experimental design.

Set #	Property Valence	Training State	Test
1	Positive (e.g., "Makes Feppy taller")	Whole familiar (e.g., lettuce)	Whole familiar (x2) Sliced familiar (x2) Whole unfamiliar (x2) Sliced unfamiliar (x2)
2	Positive (e.g., "Gives Feppy strength")	Sliced familiar (e.g., orange)	Whole familiar (x2) Sliced familiar (x2) Whole unfamiliar (x2) Sliced unfamiliar (x2)
3	Negative (e.g., "Makes Feppy throw up")	Whole familiar (e.g., lemon)	Whole familiar (x2) Sliced familiar (x2) Whole unfamiliar (x2) Sliced unfamiliar (x2)
4	Negative (e.g., "Gives Feppy pimples")	Sliced familiar (e.g., broccoli)	Whole familiar (x2) Sliced familiar (x2) Whole unfamiliar (x2) Sliced unfamiliar (x2)

36 stimuli, 2 sets of 9 fruits (1 training picture and 8 test pictures) and 2 sets of 9 vegetables (1 training pictures and 8 test pictures).

The doctors told me that this food (showing a training picture without naming it) makes Feppy throw up (example when the property was negative). Do you see Feppy? He looks like he just

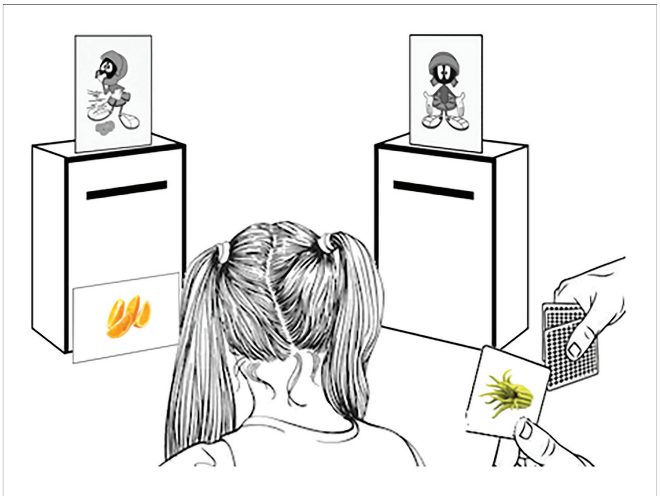

FIGURE 3 | Apparatus of the property generalization task.

threw up and has a tummy ache, you see?" We then place the training picture in front of the mailbox that contains foods that make Feppy throw up. "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 mailbox of foods that make Feppy throw up. If not, you will have to put it in the other mailbox. Do you think this (pointing to the first test picture without naming it) goes in the mailbox of foods that make Feppy throw up or in the other mailbox?" The same question was then asked for the next seven test pictures, shown successively. Each child carried out this sorting task for all food sets, one after the other, without any feedback. For each set, the experimenter changed the picture of Feppy to illustrate another property (e.g., the "makes Feppy throw up" picture was replaced by the "gives Feppy strength" picture). Then, the experimenter asked the child: "Do you see Feppy now? He looks really strong, he is showing his muscles, you see?" The order in which both sets and within each set the test pictures were presented was pseudo-randomized and counterbalanced across children.

Identification Task

Following the induction task, children were asked to name the 16 familiar test pictures they encountered during the experimental task. For each item, a score of 1 was given for the correct name and 0 for an error (i.e., not being able to give the name or incorrect name). We then assigned for each child a global percentage of identification (mean = 86.9%, *SD* = 15.0), a percentage of identification of whole tests (mean = 88.2%, *SD* = 20.3) and a percentage of identification of sliced tests (mean = 85.6%, *SD* = 20.2).

RESULTS

Induction Task

For each trial, a score of 1 was given when children generalized the property to the test and placed it into the corresponding mailbox, and a score of 0 was given when the child did not generalize the property to the test. We tested our predictions with a generalized linear mixed-effects model (Baayen et al., 2008), using a *Binomial* distribution, to analyze the probability of generalizing the property, using the lme4 package, function glmer, in the R environment (Bates et al., 2015). As shown in **Table 3**, the models were constructed by iteratively adding predictive variables to the null model (M0, the intercept and no predictor). Based on the procedure of decreasing the Akaike Information Criterion (AIC; Hu, 2007), we constructed the model that was the best fit to the data with the probability of generalization as the outcome measure. Our best fit model (M8) contained random effects (participants), and within-subjects fixed-effects: Test (Whole familiar, Sliced familiar, Whole unfamiliar, and Sliced unfamiliar), Valence (Positive and Negative), Neophobia (continuous factor), and the two-way interactions, Test × Valence and Neophobia × Valence. This model explained 14.3% of the variation across our sample, as demonstrated by the adjusted R^2. We report the ANOVA output results for the models throughout. **Table 4** shows the descriptive statistics for the probability of generalizing the positive and negative properties to the tests. We also conducted Wilcoxon tests to determine whether the probability to generalize the properties to the different tests was significantly different from chance (0.5).

TABLE 3 | The goodness of fit of the generalized linear mixed models.

	Model	*Df*	AIC	Pseudo R^2	*p*
M0	1		2788.8	0	
M1	… + Test	3	2782.7	0.007	0.008
M2	… + Test + Valence	4	2779.5	0.010	0.024
M3	… + Test + Valence + Premise state	5	2781.5	0.010	0.920
M4	… + Test + Valence + Neophobia	5	2777.5	0.013	0.045
M5	… + Test + Valence + Neophobia + Pickiness	6	2779.3	0.013	0.676
M6	… + Test * Valence + Neophobia	8	2562.8	0.140	<0.001
M8	… + Test * Valence + Neophobia * Valence	9	2560.7	0.143	0.043
M9	… + Test * Valence * Neophobia	15	2566.6	0.145	0.415

M8 was the best model given the data because it had the lower AIC.

First, the results revealed a significant effect of Test [χ^2 (3) = 9.50, $p = 0.023$, $\Delta R^2 = 0.007$].[1] *Post-hoc* Tukey comparisons revealed that children generalized the properties to the Sliced unfamiliar tests (*M* = 0.482, *SD* = 0.280) significantly less often than they did to Whole familiar (mean = 0.577, *SD* = 0.277, $p = 0.013$) and Sliced familiar tests (mean = 0.563, *SD* = 0.297, $p = 0.05$). There was also an effect of Valence [χ^2 (1) = 5.11, $p = 0.024$, $\Delta R^2 = 0.003$]. Children generalized the positive properties (mean = 0.564, *SD* = 0.162) significantly more often than they did for the negative properties (mean = 0.510, *SD* = 0.151). As shown in **Figure 4**, there was a significant interaction effect between Test and Valence [χ^2 (3) = 198.03, $p < 0.001$, $\Delta R^2 = 0.127$]. A Tukey a *posteriori* test revealed

[1]Delta R^2 are reported in lieu of η^2 for the mixed models in this paper, since no satisfactory method is currently available to estimate effect sizes on mixed models (Westfall et al., 2014).

that children generalized significantly more the positive properties to familiar tests than they did for negative properties (all $p < 0.001$). A reverse pattern was found for Whole unfamiliar tests, children generalizing significantly less often the positive properties (mean = 0.318, SD = 0.369) than they did for the negative properties (mean = 0.737, SD = 0.329, $p < 0.001$). Interestingly, children generalized significantly more the positive properties (mean = 0.480, SD = 0.364) and less the negative properties (mean = 0.482, SD = 0.341) to Sliced unfamiliar tests than they did to Whole unfamiliar tests (all $p < 0.01$).

Second, a significant effect of Neophobia was found [χ^2 (1) = 4.02, p = 0.045, ΔR^2 = 0.003]. Food neophobia scores and the probability to generalize the properties were significantly positively correlated (as attested by Spearman's correlation coefficient, r = 0.195, p = 0.029). As shown in **Figure 5**, there was a significant interaction effect between Neophobia and Valence [χ^2 (1) = 4.09, p = 0.043, ΔR^2 = 0.003]. Food neophobia scores were positively correlated with the probability to generalize the negative properties (r = 0.282, p = 0.005, see the red line in **Figure 5**).

TABLE 4 | Mean probability to generalize positive and negative properties (SD in brackets).

Test	Positive	Negative
Whole familiar	0.750 (0.271)**	0.411 (0.366)*
Sliced familiar	0.710 (0.325)**	0.409 (0.339)**
Whole unfamiliar	0.318 (0.369)**	0.737 (0.329)**
Sliced unfamiliar	0.480 (0.364)	0.482 (0.341)

Wilcoxon tests compared children's probability to generalize the properties against chance (0.5).
**p < 0.025; **p < 0.001.*

Identification

Children' global percentage of identification was significantly above the arbitrarily fixed 70% accuracy threshold that served to select the familiar stimuli (as attested by a Wilcoxon test, mean = 86.9%, SD = 15.0; W = 2,188, $p < 0.001$, d = 0.97). The same pattern was found for whole (mean = 88.2%, SD = 20.3; W = 2,198, $p < 0.001$, d = 0.92) and sliced familiar foods (mean = 85.6%, SD = 20.2; W = 2,158, $p < 0.001$, d = 0.78). Paired-samples t-test did not reveal any difference in identification performances between food processing states (W = 220, p = 0.236).

Finally, children's percentage of identification was only significantly positively correlated with their Age (r = 0.320, $p < 0.001$). Since no effect of Food Rejections was found in the identification task, these results suggest that the previous

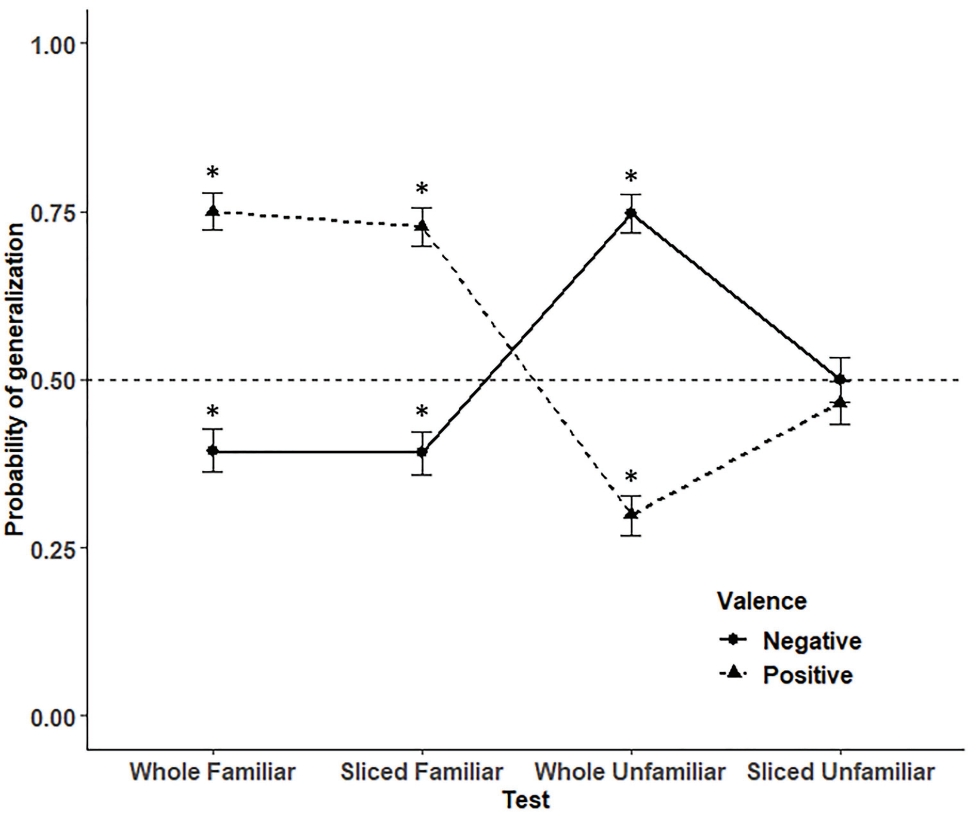

FIGURE 4 | The probability to generalize the properties as a function of Test and Valence. Stars represent significant differences against 0.5. Vertical bars represent MSEs.

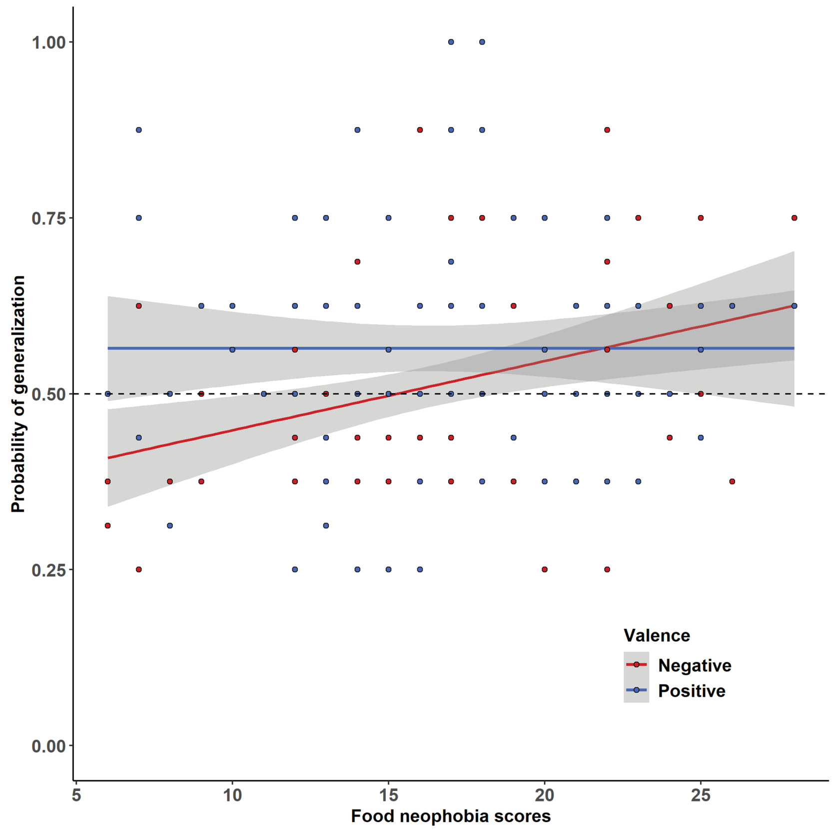

FIGURE 5 | The probability of properties generalization as a function of Food Neophobia scores [as attested by the Child Food Rejection Scale (CFRS)] and Valence.

result found in inductive reasoning did not arise from differences in children's ability to recognize the foods given.

DISCUSSION

This paper studied children's generalization of positive and negative food properties, as a function of their food rejection dispositions. We contrasted familiar and unfamiliar foods and their processing states, whole and sliced. To the best of our knowledge, this experiment is the first to manipulate food familiarity and processing states, and to assess their interaction with food rejection tendencies. Our data revealed clear dissociations between the generalization patterns for positive and negative properties as a function of food familiarity.

Our results confirmed former findings showing that children reason on a positive-negative distinction in that they associate familiar foods with positive properties (i.e., above chance) and not with negative properties (i.e., below chance; H1). These results expand previous findings of Nguyen et al.' studies (Nguyen and Murphy, 2003; Nguyen, 2007, 2008; Thibaut et al., 2016) as our training items were also fruits and vegetables known to be healthy, which were associated with a negative property. This result not only highlights that children effectively use their previous knowledge of foods, but also that they are capable to adapt to new contrasting information (i.e., a supposed healthy food having negative properties).

Unfamiliar foods revealed a contrasting pattern of results. Children were cautious in the case of unfamiliar test stimuli. Indeed, for whole unfamiliar foods, they generalized positive properties under chance but generalized negative properties above chance. Without any knowledge (positive or negative) of these foods, children seem to have conjectured that whole unfamiliar foods might be threatening. Yet, regarding the sliced unfamiliar tests, children generalized more positive and less negative properties to these foods than they did to the whole unfamiliar tests. Thus, children used food processing as a relevant dimension when reasoning about unfamiliar foods (Lafraire et al., 2020). Here, even as subtle transformations not affecting food's organoleptic properties directly (Foroni et al., 2013; Coricelli et al., 2019), food processing might have decreased children's apprehension regarding unfamiliar foods. Children showed that they were sensitive to the state of the food as regard to its edibility (Foroni et al., 2013; Coricelli et al., 2019; H2). Nonetheless, children's pattern of generalization for both positive and negative properties was at chance level for sliced unfamiliar test foods. Therefore, we cannot firmly conclude that the food processing state totally removed children's cautiousness regarding unfamiliar foods. Using advanced culinary food transformations might help to disambiguate the perceived edibility of unfamiliar foods as a function of the degree of food processing.

In addition, our study adds important information to previous studies such as the one by Rioux et al. (2018a), which showed that neophobic children face generalization problems. Indeed, as hypothesized neophobic children generalized the negative properties more often than their less neophobic counterparts (H3), whereas we did not find any effect of food neophobia on positive property generalization. Interestingly, contrary to our expectations, this generalization of the negative properties was not specific to the unfamiliar tests. This suggests that when facing threatening risks, neophobic children face a generalization problem and can extend negative experiences to other foods, even familiar ones. This interpretation is in line with Crane et al.'s (2020) recent claim that neophobic individuals are cautious decision-makers who favor safe decisions (i.e., generalizing the negative properties more broadly) to prevent more costly errors (i.e., not generalizing the negative properties to potentially harmful substances). Finally, similarly to Rioux et al. (2018a), we did not find any significant effect of food pickiness. Considering that a high score on the neophobia subscale (Rioux et al., 2017) means that parents *Strongly agreed* that their child shows cautiousness or even distress toward foods, it is not surprising that these children strongly generalized negative properties. However, only the notions of liking and acceptance are considered in the pickiness subscale, which, contrary to neophobia, are not directly related to the perceived risk of foods.

CONCLUSION

In conclusion, our results provide evidence in favor of our hypotheses and have potential implications for knowledge-based food education interventions. Indeed, it appears that children have conceptions about the health consequences of familiar foods. They are also very cautious when dealing with unfamiliar whole foods. Whereas children do not extend the positive properties to the unfamiliar foods, they would for the negative properties. Furthermore, it appears that children are also sensitive to the processing state of foods. While being categorical for whole unfamiliar foods, with sliced unfamiliar foods children did not know whether or not they should generalize the positive and negative properties. Finally, our results contribute to the growing evidence associating food rejection dispositions with food domain generalization problems. Here, neophobic children generalized more the negative properties than their less neophobic counterparts. This finding suggests that there is a need to be aware of children's interindividual differences when providing information on food effects.

Nonetheless, our study had several limitations. First, our sets were generated on a single taxonomic category (e.g., fruits), including the unfamiliar foods. It would be of interest to investigate children's generalization of health-related properties with other food categories that are less prone to rejections (such as starchy foods). Second, one limitation of the present study is the fairly low number of properties illustrating the positive and negative conditions. Increasing the number of properties to generalize is important if we want to better understand whether children's reasoning of positive and negative properties is general or specific to the kind of food health-related properties provided. Another limit is the low number of trials per each experimental condition. Indeed, we had to comply with the limited repertoire of foods children are familiar with, while reducing the perceptual similarities between trainings and tests as much as possible. Third, we did not control for children's liking of the presented foods. Some children may have generalized the negative properties on the basis of aversive memories related to previous experiences with familiar foods. Finally, the design was complex which might affect the interaction between variables.

Despite these limitations, we believe that the present experiment opens up promising new research avenues, and sheds light on the relationships between children's food reasoning and food rejections. Future research might then assess the potential developmental effect to determine when and to what extent children might be sensitive to food processing as an edibility cue. In the present experiment, foods were either whole or cue, with minimal human transformations. However, a strategy worth investigating would be to manipulate the degree of food processing in a broader sense, including cooking for instance. Another promising line of research would be to explore the effect of stressing the intention of the chef who prepares food, or why preparing food is an important process. Indeed recent studies revealed that children who took part in culinary activities showed increases in their food acceptance (Chu et al., 2014; Allirot et al., 2016; DeJesus et al., 2019). By exposing children to food transformation processes of a raw product by interaction with a chef or parents, children's food risk perception may decrease which could lead to increased acceptance of the given food.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by official agreement between the Academia Inspection of the French National Education Ministry and the University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

DF, JL, and J-PT conceived the hypotheses and the design of the study. DF collected the data and performed the statistical analyses. All the authors contributed to the manuscript writing, read and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Chapter 6. Drivers of neophobic children' strategy in the food domain: gaps of knowledge and uncertainty.

The results of the previous chapter revealed that higher levels of food neophobia were associated with heightened caution regarding stimuli edibility. More precisely, that neophobic children overgeneralized a food's negative properties even in situations of reduced uncertainty (i.e., regardless of the foods being familiar and/or sliced).

This chapter presents two experiments, designed to determine if both notions of fear and lack of knowledge could be investigated simultaneously using the SDT framework (Crane et al., 2020).

Experiment 1 was a forced-sorting task in which 120 children had to discriminate between foods and similar-looking nonfoods. Results revealed that levels of neophobia were predictive of the number and the kind of mistakes children made. More precisely, children with high levels of food neophobia made more mistakes and compared to more neophilic children, they favored making "it is inedible" mistakes, thus being more cautious.

According to the existing findings, food processing cues such as slicing reduce children's uncertainty as regard to stimulus edibility (e.g., Chapter 5). However, according to Rioux & Wertz (2021), only the more neophilic children may be sensitive to such cues as a safety signal.

Therefore, Experiment 2 tested 137 children to extend the findings from Experiment 1, with the addition of the food processing variable, contrasting whole and sliced stimuli. Results confirmed that children with higher levels of food neophobia were less accurate and biased to make more "it is inedible" mistakes. An important additional finding of the second experiment is that neophilic children adopted a more liberal bias for sliced stimuli than for whole stimuli (i.e., they considered most of the sliced stimuli as food). However, the state of the stimuli did not affect the neophobic children.

Experiment 2 has been accepted in Proceedings of the Annual Meeting of the Cognitive Science Society (escholarship.org/uc/item/52q4011b).

6.1. Introduction

Why would we avoid patting an animal we see for the first time? Why are we seeking information about a restaurant before making a reservation? Why do we not pick up an unfamiliar fruit from its tree to stave our hunger? Fearful reactions towards what we do not know, being stimuli or situations, are referred to as *neophobia* (Crane et al., 2020; Pliner et al., 1993; Rozin, 1979). Neophobia is a widespread disposition in human and non-human animals. Importantly, there is often a large degree of individual variation in neophobia, with some individuals consistently showing higher levels of neophobia than others (e.g., Pliner & Hobden, 1992). Whereas neophobic individuals show aversive reactions (e.g., avoidance) towards every stimulus or situation they are uncertain about, *neophilic* individuals are on the contrary attracted, or at least not reluctant, to experience uncertain stimuli or situations.

A great deal of interest about neophobia comes from its particular expression in the food domain, especially in human children (see Dovey et al., 2008 and Lafraire et al., 2016a for reviews). This is because high levels of food neophobia can have negative consequences for normal and healthy development by hindering the consumption of fruits and vegetables (Woodside et al., 2013). Furthermore, although food neophobia has an increased prevalence during childhood, such dietary habits and behaviors prevail well into adulthood (Nicklaus et al., 2005). It is therefore critical to explain young children's resistance to try new foods and to identify what would contribute to overcoming this reluctance.

Recently, food neophobia has been explained by gaps of knowledge about foods (Dovey et al., 2008; Harris, 2018; Lafraire et al., 2016a; Rioux et al., 2016). Knowledge allows recognition (e.g., this is a "carrot"), categorization, and inference-based decision-making (Murphy, 2002). In the food domain, when presented with a known food such as a carrot, children can rely on their knowledge about previous carrots they encountered and ate to infer that it is edible and thus safe to eat. However, if children have a narrow knowledge of carrots, they may fail to represent the carrot (because the actual carrot is purple and they think that carrots should display the more typical orange) as a *carrot* or a *vegetable*, or maybe even as a *food*. If children fail to recognize the given food, he/she might avoid eating it, missing the opportunity to learn that the purple carrot like the more typical orange ones is sweet, edible, rich in vitamins, etc. Recent findings corroborate this proposal (e.g., Foinant et al., 2021a; Pickard et al., 2021; Rioux et al., 2016; Rioux et al., 2017a). For instance, Rioux et al. (2016) demonstrated that levels of food neophobia in preschool-aged children were inversely associated with their ability to discriminate vegetables from fruits. In sum, food neophobia and knowledge are closely intertwined.

Thus, it has been proposed that food neophobia could be reduced by building children’s knowledge about foods to allow for easier categorization, when subsequently presented with the same or similar foods (Aldridge et al., 2009; Rioux et al., 2018a). A considerable body of research has investigated whether repeated exposure to fruits and vegetables might enhance children’s acceptance and reduce rejection (for reviews see Cooke, 2007; Keller, 2014). There is substantial evidence for successful interventions, in controlled (Birch & Marlin, 1982; Brich et al., 1987) and ecological settings like school or home environments (Mustonen & Tuproma; 2010; Park & Cho, 2015). A novel type of health intervention, knowledge-based, appears promising in enriching children’s understanding of food and subsequently boosting food acceptance (Gripshover & Markman, 2013; Nguyen et al., 2011). However, if these interventions often lead to increased subsequent acceptance of the targeted food, they might not be efficient for highly neophobic children (De Wild et al., 2016; Rioux et al., 2018a; Zeinstra et al., 2016). For instance, up to twenty-seven exposures can be necessary before these children accept to taste a targeted food (William et al., 2008), whereas studies suggest usually an average of 8 to 15 exposures (Cooke, 2007; Wardle et al., 2003). Rioux and colleagues’ study (2018a) showed that in situations of increased uncertainty (i.e., exposure to atypically colored vegetables), neophobic children consumed a significantly lesser amount of the exposed foods, as compared to their more neophilic counterparts.

A plausible explanation for the inefficiency of such interventions for neophobic children is that knowledge learning is impaired by their fear of the situation. Indeed, children are presented with fruits and vegetables, often new or atypical, before being asked to eat them. However, for neophobic children, such situations may trigger strong emotional and physiological responses (McFarlane & Pliner, 1997; Pelchat & Pliner, 1995; Pliner & Loewen, 2002).

Numerous studies have demonstrated that food neophobia is a true phobia (see Maratos & Sharpe, 2018 for a review). For instance, it has been shown that individuals with high levels of neophobia display stronger typical physiological fear responses to new foods, such as galvanic skin response and an increase in pulse or respiration rhythm, as compared to their more neophilic counterparts (Raudenbush & Capiola, 2012). Furthermore, food neophobia is often connected to an increase in anxiety (Galloway et al., 2003), or even disgust over new foods (Brown & Harris, 2012; Martins & Pliner, 2006). Recently, Maratos and Staples (2015) showed that, although all children demonstrate attentional biases (e.g., facilitated visual engagement) toward new foods, these biases were heightened in children displaying higher levels of food neophobia. All three components (anxiety, disgust, or attentional biases) are standard markers of phobias (Cisler & Koster, 2010). Other findings on the expectations (e.g., danger) associated with new foods support the idea that food neophobia represents a genuine fear response (e.g., Johnson et al., 2018; Pliner et al., 1993). For instance, Johnson et al. (2018) asked children between 3 and 5 years of age their reasons to avoid tasting new foods. More than half of children's justifications referred to the fear of negative consequences following ingestion (e.g., nausea, falling sick, choking, dying). An additional finding of their study is that neophobic children (i.e., children less willing to try the new foods in the experiment) rated the foods less favorably than more neophilic children. Additionally, higher levels of food neophobia have been associated with tactile defensiveness (i.e., withdrawal responses to tactile stimuli or overreactions to the experiences of touch; Smith et al., 2005), lower levels of sensation-seeking (i.e., levels in the strength of stimulation to reach the appropriate level of awakening; Galloway et al., 2003) and approach tendencies to novelty (i.e., children who are low in approach tend to show negative affect toward new stimuli and withdraw from them; Moding et al., 2014).These different findings highlight the difficulties neophobic children may experience when exposed to new foods and which could lead them to withdraw from the learning opportunities.

Therefore, before trying to fill children's knowledge gaps about food, it might be first necessary to investigate neophobic children' strategies toward what they perceived as dangerous unbearable situations.

6.2. The current research

To better understand food neophobia and to construct effective interventions for increasing the consumption of fruits and vegetables in young children, it appears necessary to investigate the twofold driver of the phenomenon: the problem of gaps in knowledge, but also the withdrawal strategies when facing uncertain food situations. Indeed, the important issue for any eater is to consume edible foods and avoid non-edible ones. When foods are novel, which is often the case for young children, it is important to accept healthy foods and to refuse non-edible ones. However, sticking to the same subset of familiar foods might lead to a decrease of dietary variety or on a more daily basis, to avoid the available foods in a meal. For children with food rejection, the problem is that the number of misses might increase at the expense of hits.

The Signal Detection Theory (SDT; Macmillan & Creelman, 2004) provides a framework for studying simultaneously both drivers of food neophobia, gaps of knowledge and withdrawal strategies (Crane et al., 2020). SDT characterizes how perceivers separate the "signal" from distractors, referred to as the "noise", according to two underlying psychophysics components, sensitivity and strategy. Sensitivity is a perceiver's ability to discriminate the signal from the noise (e.g., foods versus nonfoods). Sensitivity depends upon how well the perceiver can discriminate between stimuli and his/her ability to apply prior knowledge. Conversely, the strategy is this perceiver's tendency, when categorization cannot be avoided, to decide that stimuli are signal or noise. The strategy may vary as a function of the relative costs of missing the signal (referred to as *misses*) and responding to the noise as if it were the signal (referred to as *false alarms*). For example, if the perceiver is asked to decide whether stimuli are blueberries (the signal) or deadly nightshades (the noise), he/she might treat equivocal stimuli as deadly nightshades more often than as blueberries (i.e., a conservative strategy). When a perceiver has a propensity to categorize any stimulus as the noise his/her strategy is described as conservative. If instead, he/she categorized as the signal any stimulus it is referred to as a liberal strategy. Critically, it is assumed that sensitivity and strategy are independent.

To apply Signal Detection Theory to food neophobia we designed two edibility categorization tasks because such tasks are characterized by asymmetrical costs that might reveal children's response strategies when confronted with risk in the food domain. Indeed, in such a task mistaking a non-edible item for an edible one is not equivalent to mistaking an edible item for a non-edible one, the first mistake might lead to sickness or death whereas the second one is just preventing you from getting some nutrients. The present task builds on Lafraire et al.'s (2016b). The authors tested young children's abilities to discriminate fruits and vegetables from nonfoods matched on color and shape (e.g., a red tomato and a red Christmas ball). The children correctly categorized 80% of foods as edible, however, they mistook nonfoods as food in 50% of the cases (i.e., false alarms), which indicates a liberal categorization strategy, considering a majority of the stimuli as foods.

Experiment 1 was a forced-choice task in which children between 4 and 6 years had to discriminate between foods and similar-looking nonfoods. Experiment 2 included processed foods and nonfoods to test the influence of different levels of perceived uncertainty on children's categorization. By level of perceived uncertainty, we mean that food processing (e.g., sliced foods) might be seen as safer than raw foods, because it is a sign of human intervention. Previous studies have shown that both adults (Coricelli et al., 2019) and children (Foinant et al., 2021) use these cues when they make decisions about consumption.

We predicted that children's food neophobia is negatively correlated with their ability to discriminate foods from nonfoods (H1). We also expected neophobic children to adopt a more conservative strategy, making more nonfoods responses when making mistakes than more neophilic children (H2).

Experiment 2 is a replication of Experiment 1, with the addition of the food processing variable. We hypothesized that considering the evidence suggesting that food processing cues signal safety (e.g., Foinant et al., 2021), children would adopt a more liberal strategy for sliced stimuli than for whole stimuli (H3). Furthermore, recent findings showed that infants who displayed a higher behavioral approach to sliced fruits and vegetables were more likely to exhibit lower food neophobia a year later (Rioux & Wertz, 2021). Therefore, we expected an interaction between food neophobia and the state of the stimuli (whole and sliced), with neophilic children adopting an increased liberal strategy for sliced stimuli as compared to their more neophobic counterparts (H4).

6.3. Experiment 1

6.3.1. Participants

Participants were 120 children (63 girls and 57 boys; age range = 48.20 to 76.20 months; mean age = 63.50; SD = 7.29). This sample size was chosen to match previous studies that found an effect of food rejection on categorization (e.g., Foinant et al., 2021; Pickard et al., 2021; Rioux et al., 2016). They were predominantly Caucasian and came from middle-class urban areas. Informed consent was obtained from their school and their parents. The procedure was in accordance with the Declaration of Helsinki and followed institutional ethics board guidelines for research on humans.

6.3.2. Materials and procedure

To measure children's food neophobia we used the Child Food Rejection Scale (CFRS; Rioux et al., 2017b). The CFRS was developed to assess, by hetero-evaluation, 2-to-7-year-old children's food rejection on two subscales: one is measuring children's food neophobia and one is measuring their pickiness. The use of a scale allowing the distinction between food neophobia and pickiness was important. Indeed, pickiness, contrary to neophobia, is another form of food rejection that is less connected to risk and uncertainty in the food domain (for reviews see Dovey et al., 2008 and Lafraire et al., 2016a).

On a 5-point Likert-like (*Strongly disagree*, *Disagree*, *Neither agree nor disagree*, *Agree*, *Strongly agree*), caregivers were asked to rate 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*"). Each answer was then numerically coded with high scores indicating higher food neophobia and pickiness (scores could range from 6 to 30 for neophobia, *M* = 14.9, *SD* = 5.06; from 5 to 25 for pickiness, *M* = 16.4, *SD* = 4.92; and global food rejection from 11 to 55, *M* = 31.4, *SD* = 8.88).

Children were tested individually for approximately 10 minutes in a quiet room at their school and told they will play a computer game. The experiment consisted of two parts run successively and in a constant order for all the children.

The categorization task was presented on a computer and designed with Open Sesame. Children were seated at 50 cm from a computer screen. Children were instructed to respond as quickly and as accurately as possible by pressing the target button whenever a food picture appeared and by pressing the non-target button when a nonfood picture appeared. Children were told: 'I need your help; I have many things that look like foods but sometimes are not foods at home. Yoshi who comes to visit me always puts anything in his mouth. But we do not want him to get sick because he ate something that is not healthy for him. Do you agree with me? Yoshi should not get poisoned. Can you help me to tell him what he can eat and what he cannot eat? You press this button (pointing to the button) when you see something that can be eaten. When you see something that cannot be eaten you press this other button. But be careful, Yoshi should not put things in his mouth that cannot be eaten". We used a puppet to decrease the risk of children using their preferences and consumption habits to answer the task. The task started with two training phases of 4 trials each (2 edible plant-based foods and 2 nonfoods). In the training phase, we explained the meaning of "things that cannot be eaten" that were real non-edible items, and that we did not refer to poisonous or unlikable (by children' standards) foods. During the training phases children also trained themselves with the response buttons and feedbacks were provided by the experimenter when they did a mistake. Failed trials were repeated. The test phase consisted of 10 target (i.e., the signal) and 10 non-target (i.e., the noise, distractors) trials presented in random order. All foods were fruits and vegetables as these two categories are the main target of food rejection (Dovey et al., 2008). Besides, the foods and nonfoods used were individually matched on color and shape (see Figure 7 for examples). For each trial, a stimulus (apparent size: 20° x 13.5°) was displayed until the child's answer.

Figure 7. Examples of stimuli

6.4. Data analyses

The type of response for each food stimulus (hit or miss) and each nonfood stimulus (correct rejection or false alarm) was recorded. Each participant was assigned a hit score (i.e., number of food stimuli categorized as food), a miss score (i.e., number of food stimuli categorized as nonfood), a correct rejection score (i.e., number of nonfood stimuli categorized as nonfood), and a false alarm score (i.e., number of nonfood stimuli categorized as food). Hit, miss, correct rejection, and false alarm scores could vary between 0 and 10. These scores were used to calculate a categorization performance score A', and a categorization strategy score Beta, derived from SDT (Macmillan & Creelman, 2004), adapting them to experiments based on small numbers of stimuli (see, Rioux et al., 2018a). SDT is used to analyze data derived from tasks where a decision is made regarding the presence or absence of a signal (i.e., the foods) embedded in noise (i.e., the perceptually similar nonfoods). The categorization performance score A' represents the distance between the mean of the signal distribution and the mean of the noise distribution. The greater the A' the better an individual is at discriminating the signal from the noise. A' ranged from 0 to 1, with 0.5 indicating responses at chance level, and 1 maximum discriminability.

$$A' = log\left[\frac{N_H + 0.5}{N_M + 0.5}\right] - log\left[\frac{N_{FA} + 0.5}{N_{CR} + 0.5}\right]$$

The categorization strategy score Beta represents the individual's strategy to categorize stimuli as the signal rather than the noise. Beta ranged from −1 to 1, with negative values indicating a liberal strategy (i.e., children tending to categorize any stimulus as food), and positive values indicating a conservative strategy (i.e., children tending to categorize any stimulus as nonfood).

$$\boldsymbol{Beta} = -\boldsymbol{log}\left[\frac{\boldsymbol{N_H + N_{FA} + 0.5}}{\boldsymbol{N_M + N_{CR} + 0.5}}\right]$$

With N_H, N_M, N_{FA}, and N_{CR} corresponding to the numbers of hits, misses, false alarms, and correct rejection, respectively.

6.5. Results

To test the hypothesis that children's categorization was impacted by their food neophobia, we assessed A' and Beta (results set out in Table 1).

Given the relatively broad age range of the children reported in this study, preliminary Spearman's correlations were run to test for significant associations between children's age with the study's key variables (children's food neophobia scores, categorization A' and Beta). Children's age was significantly positively correlated to A' (r = .177, p =.053), and Beta (r = .190, p =.038). In addition, independent t-tests examined differences in children's age, food neophobia scores, and categorization scores for girls and boys. The t-tests did not reveal any differences between girls and boys on any of these measurements (p > .05). In view of the findings from these preliminary analyses, partial correlations controlling for children's age were run on the sample as a whole.

	Children (*n* = 120) *M* (*SD*)
Age (in months)	63.5 (7.29)
Global food rejection	31.4 (8.88)
Food neophobia	14.9 (5.06)
Food pickiness	16.4 (4.92)
Hit	79.8% (17.0%)
Miss	20.2% (17.0%)
Correct rejection	74.7% (16.8%)
False alarm	25.3% (16.8%)
A'	.714 (.120)
Beta	-.028 (.116)

Table 1. Descriptive statistics for age, food rejection scores, and categorization scores.
SD: standard deviation

We performed Spearman correlations between children's food neophobia scores and categorization scores, after controlling for age. The results revealed that food neophobia scores were significantly related to both A' and Beta. Consistent with previous findings (e.g., Rioux et al., 2016), food neophobia was negatively associated with children's discrimination (A'; r = -.193, p =.036). Furthermore, as predicted food neophobia was also positively correlated with their Beta (r = .186, p =.042), which shows that increased misses were preferred over hits. This means that highly neophobic children adopted a more conservative strategy than their more neophilic counterparts.

6.6. Discussion Experience 1

Experience 1 investigated both drivers of children's food neophobia (i.e., gaps of knowledge and withdrawal strategy from an uncertain food situation) could be investigated simultaneously. Our results are the first ones demonstrating that children with high food neophobia scores exhibited poor sensitivity as compared to children with low food neophobia scores, in discriminating foods from nonfoods. Further, using a task with asymmetrical costs in categorization errors (i.e., foods versus nonfoods), our data are the first to show that high levels of food neophobia predict a safer categorization strategy. Indeed, neophobic children displayed a more conservative decision strategy than other children. These children categorized foods as nonfoods even though they were actual edible substances.

6.7. Experience 2

In the following experiment, we aim to investigate whether cues of food processing could reassure children about stimuli edibility. Indeed, according to recent evidence, food processing is a visual cue that can reduce uncertainty about edibility and thus promote feelings of safety in the food domain (Coricelli et al., 2019; Foinant et al., 2021; Foroni et al., 2013, 2016; Rioux & Wertz, 2021). Contrary to unprocessed food that is natural food with no signs of human intervention, processed food is defined as food that exhibits signs of human interventions (e.g., cooked, sliced). For instance, Foinant et al. (2021) showed that children between 4 and 6 years generalize significantly fewer negative health properties (e.g., "makes Feppy throw up", p.5) to a new food if it is sliced compared to whole. Additional evidence suggests that even infants perceive cues of food processing as signaling food safety. Rioux and Wertz (2021) measured 7-to-15-month-old infants' social looking time towards adults (a strategy employed by infants who seek out social information when confronted with potential harmful stimuli) towards whole and sliced plant foods. The authors reported that infants engaged in significantly less social looking before touching the processed plant foods and sometimes, they even put these foods in their mouths, a behavior never reproduced with the whole plant foods. Interestingly, the infants who displayed higher behavioral avoidance of sliced fruits and vegetables were more likely to exhibit greater food neophobia a year later. In sum, these findings suggest that the contribution of the level of processing dimension in the food domain is to reduce uncertainty about edibility.

Therefore, building upon Experiment 1, we hypothesized that children would adopt a more liberal strategy for sliced stimuli than for whole stimuli (H3). Furthermore, we expected an interaction between food neophobia and the state of the stimuli (whole and sliced), with neophilic children adopting an increased liberal strategy for sliced stimuli as compared to their more neophobic counterparts (H4).

6.7.1. Participants

Participants were 137 children (77 girls and 60 boys; age range = 57.14 to 72.07 months; mean age = 64.50; *SD* = 3.72).

6.7.2. Materials and procedure

As in Experiment 1, the caregivers filled out the CFRS (food neophobia scores, *M* = 15.3, *SD* = 5.28; food pickiness scores, *M* = 16.8, *SD* = 4.41; and global food rejection scores, *M* = 32.1, *SD* = 8.81).

The procedure for the categorization task was the same as Experiment 1, however, we introduced the factor "item state" (whole versus sliced items) in the design. The test phase consisted of 16 target (i.e., the signal) and 16 non-target (i.e., the noise, distractors) trials presented in random order. The target trials were composed of 8 whole edible food items and 8 sliced edible food items. The non-target trials were composed of 8 whole non-edible items and 8 sliced non-edible items (see Figure 8 for examples).

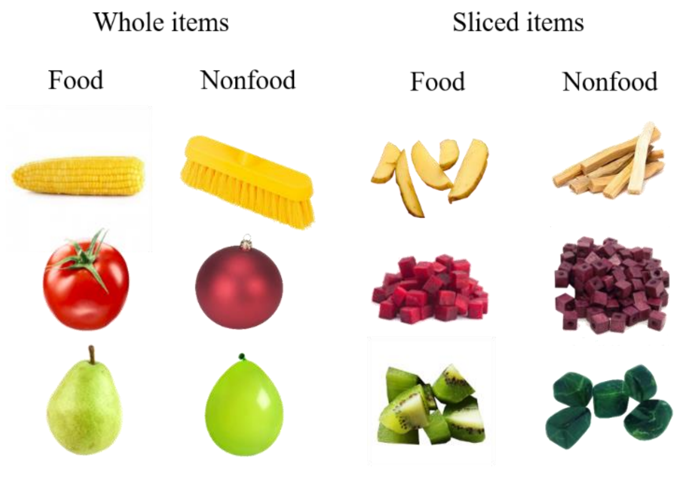

Figure 8. Examples of stimuli

6.8. Results

To test the hypothesis that children's categorization was influenced by their level of food neophobia and items states (Whole and Sliced), we assessed A' and Beta (results set out in Table 2).

We ran linear mixed-effects models with children serving as a random factor to account for shared variances within subjects, whereas item state (Whole and Sliced) and food neophobia scores (continuous) were modeled as fixed effects.

	Children (*n* = 137) *M* (*SD*)
Age (in months)	64.50 (3.72)
Global food rejection	32.1 (8.81)
Food neophobia	15.3 (5.28)
Food pickiness	16.8 (4.41)
Hit	91.8% (9.36%)
Miss	8.2% (9.36%)
Correct rejection	68.3% (16.5%)
False alarm	31.7% (16.5%)
Hit whole	92.6% (9.04%)
Miss whole	7.4% (9.04%)
Correct rejection whole	78.5% (15.8%)
False alarm whole	21.5% (15.8%)
Hit sliced	90.7% (13.1%)
Miss sliced	9.3% (13.1%)
Correct rejection sliced	57.9% (23.7%)
False alarm sliced	42.1% (23.7%)
A'	.743 (.092)
A' whole items	.816 (.113)
A' sliced items	.726 (.111)
Beta	-.118 (.100)
Beta whole items	-.081 (.096)
Beta sliced items	-.206 (.194)

Table 2. Descriptive statistics for age, food rejection scores, and categorization scores. *SD*: standard deviation

6.8.1. Discriminability index A'.

We ran a mixed model on children's A', with item state (Whole or Sliced), and food neophobia as predictors. Results revealed an effect of item state (F = 18.63, $p < .001$, $d = 0.74$) with significantly more accurate discriminations for whole ($M = 0.816$, $SD = 0.113$) than for sliced ($M = 0.726$, $SD = 0.111$) items. There was also a significant effect of food neophobia (F = 4.73, $p = .031$, $d = -0.35$). Food neophobia scores and A' were significantly negatively correlated (*r*

= −.205 *p* = .017). The highly neophobic children had a lower discrimination accuracy to distinguish between food and nonfood items than the more neophilic children. The model did not reveal a significant interaction effect between item state and food neophobia ($F = 2.45$, $p = .120$, $d = 0.27$).

6.8.2. Decision criterion Beta.

We ran a mixed model on children's Beta, with item state (Whole or Sliced), and food neophobia scores as predictors. Results revealed an effect of item state ($F = 32.75$, $p < .001$, $d = 0.98$) with significantly more sliced items categorized as food ($M = -.206$, $SD = .194$) than whole items ($M = -.081$, $SD = .39$), indicating that children were more willing to decide that a sliced item was a food rather than a whole item. There was also a significant effect of food neophobia ($F = 19.36$, $p < .001$, $d = 0.20$), with highly neophobic children categorizing fewer items as foods, than other children, thus being more conservative. Food rejection scores and Beta were significantly positively correlated ($r = .354$, $p < .001$). Figure 9 shows a significant interaction between item states and food neophobia scores ($F = 10.02$, $p = .002$, $d = 0.54$). Food neophobia scores were more strongly positively correlated with Beta for sliced items ($r = .346$, $p < .001$, see the blue line in Figure 9) than for whole items ($r = .205$, $p = .016$, see the red line in Figure 9). As hypothesized, the more neophilic children were more liberal for sliced items than the other children and categorized more often the sliced items as foods.

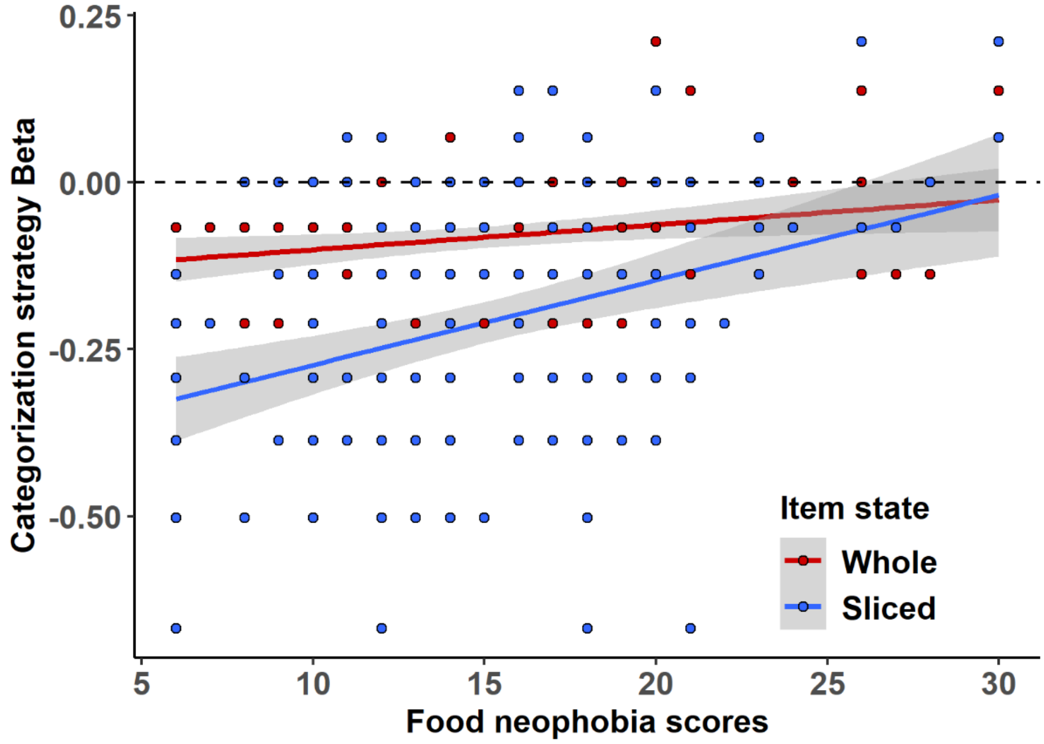

Figure 9. Children's categorization strategy scores Beta as a function of their food rejection scores and item state.

6.9. Discussion Experience 2

Experiment 2 built upon the findings from Experiment 1 and assessed the effect of the state of the stimuli with whole and sliced items. We found that higher levels of food neophobia were predictive of poorer sensitivity and a more conservative strategy. An important additional finding of this second experiment is that neophilic children adopted a more liberal strategy for sliced stimuli than for whole stimuli which was not the case for the neophobic children.

6.10. General discussion

Two experiments aimed to address simultaneously the twofold driver of neophobia: the knowledge gaps underpinning the feeling of uncertainty and the fearful reaction to perceived risk leading to withdrawal strategies.

As hypothesized, all the experiments revealed a negative association between children's food neophobia and their discrimination abilities. Building on previous results showing that children with high food neophobia had poorer discrimination abilities for fruits and vegetables (Rioux et al., 2016), our study extend them by showing that the more neophobic children had more difficulties distinguishing between the foods and nonfoods stimuli than their more neophilic counterparts.

Further, in line with our predictions, forced-choice tasks pitting a safer response (i.e., it is inedible) and a riskier response (i.e., it is edible) in an uncertain environment (i.e., nonfoods matching foods on color and shape) witnessed an association between children's food neophobia and their strategy of response. The more neophobic children made more "it is inedible" mistakes than their more neophilic counterparts. In terms of the SDT framework, neophobic children favored increased misses over false alarms (Crane et al., 2020), thus being more cautious than other children.

The results confirmed our third hypothesis, that cues of food processing serve as a signal of food safety. Children categorized more often sliced items as food than whole items, which is in line with recent evidence from Foinant et al. (2021) in a property induction task comparing raw and transformed foods. Here, children were more willing to accept even nonfoods in the food category if they were sliced, thus committing hazardous incorrect categorization. Beyond that, our data also show that food neophobia interacted with the stimuli's processing states to predict children's categorization strategy. In line with our expectations (H4), whereas the more neophobic children adopted similar response strategies for whole and sliced stimuli, the more neophilic children displayed a more liberal strategy for sliced stimuli than for whole stimuli. This result suggests that neophilic children are more sensitive to food processing as a safety cue, which can reduce perceived uncertainty as regard to stimulus edibility, than neophobic children. This interpretation is consistent with Rioux and Wertz's (2021) recent findings who observed that infants more willing to approach sliced foods were less likely to exhibit greater food neophobia later on.

In conclusion, our results provide evidence regarding the benefits of using the SDT framework to study simultaneously the twofold driver of neophobia. First, the inverse relationship between food neophobia and children's categorization abilities suggests that neophobic children have impoverished conceptual knowledge in the food domain. As suggested by several authors (Dovey et al., 2008; Harris, 2018; Lafraire et al., 2016a; Rioux et al., 2016), neophobic children may fail to recognize food stimuli because their behaviors have for a consequence to reduce their interaction with different food categories. Second, when neophobic children fail to recognize a stimulus, increased uncertainty as regard to stimuli edibility, such as in our experiments, seems to induce the adoption of cautious strategies. Such strategies allow neophobic children to mistake foods for inedible substances, however in return, they miss the opportunities to accept actual food sources.

There were several limitations to the current study. First, our food stimuli were fruits and vegetables only. It would be of interest to investigate children's categorization abilities to discriminate between foods and nonfoods with other food categories that are less prone to neophobia (such as starchy food). Another limitation is that we equated food processing with slicing. Evidence suggests that food processing is a matter of degree. For instance, other processing techniques that transform more the organoleptic properties of food such as cooking could affect edibility perception not only of neophilic children but also of neophobic children. Indeed, current evidence regarding the interaction of food neophobia and food processing is scarce and it is possible that neophobic children may need stronger safety cues to overcome their fear about the edibility of a potential food source. Despite these limitations, we believe that the present experiments open up promising new research avenues, and shed light on the possibilities to study different drivers of neophobia simultaneously. Understanding the relation between the two core notions of neophobia, namely uncertainty due to lack of knowledge and fearful reaction to perceived risk, is a critical step toward developing more effective interventions to promote healthy eating.

PART C. FOOD REJECTION AND CATEGORIZATION ABILITIES, AN EXECUTIVE FUNCTIONS-BASED APPROACH

Chapter 7. Food rejection and executive functions in young children

This chapter presents a first experiment, designed to examine the relationship between food rejection and executive functions in children between 3 and 6 years old.

A series of tests measuring the executive functions skill and world knowledge of 240 children was conducted. Children's levels of food rejection (i.e., food neophobia and pickiness) were measured using the CFRS (Rioux et al., 2017b).

The results indicated that cognitive flexibility was the only executive function found to be significantly negatively correlated with both food neophobia and pickiness. Interestingly, food neophobia was more predictive of performance on the cognitive flexibility task than food pickiness. However, whereas food neophobia was only significantly associated with cognitive flexibility, food pickiness was also associated with more difficulties on the inhibition task but better performance on the vocabulary task.

7.1. Introduction

Eating behaviors reducing dietary variety, such as food rejection, have been the focus of a large number of studies during the last decades (for reviews see Lafraire et al., 2016; Reilly, 2018; Rioux, 2020). Indeed, a balanced diet has become an important social issue because of the increasing prevalence of food-related health problems. Food rejection (e.g., food neophobia) is a common eating behavior among preschoolers but is still prevalent in adolescence and even in adulthood (Nicklaus et al., 2005). Among others, high levels of food rejection contribute to reduced consumption of fruits and vegetables (Dovey et al., 2008). Beyond that, food rejection is an important health topic because it is an obstacle against compliance to dietary recommendations and they contribute to the development of later food-related health problems. In this respect, scholars have also proposed that the consequences of food rejection on health may be curvilinear (Perry et al., 2015). This means that food rejection may be a risk factor for both anorexia nervosa (Herle et al., 2020; Kotler et al., 2001; Marchi & Cohen, 1990; Nicholls & Viner, 2009) and obesity or overweight (Carruth et al., 2004; Knaapila et al., 2015; Proserpio et al., 2018). However, studies that have systematically examined the relationship between children's food rejection and health status are scarce and have often produced conflicting results (e.g., Brown et al., 2016; Laureati et al., 2015). Despite mixed findings, food rejection can nonetheless have negative consequences on cognitive and health development (Nicklaus, 2009; Nyaradi et al., 2013). In this context, uncovering factors contributing to food rejection become of crucial importance. The present paper is the first study testing the contribution of executive functions and world knowledge.

Food rejection has been divided into two main categories, food neophobia and pickiness (Dovey et al., 2008). Food neophobia is the tendency to reject novel foods that peaks during early childhood (between 2 and 6 years). Prototypically, neophobic rejections are of children's refusal to put a novel food in their mouth, and such despite caregivers' efforts. Even a dish or a meal may be avoided if a novel food is present (Ton Nu, 1996). Food neophobia is often connected to an increase in anxiety (Galloway et al., 2003) or even disgust over novel foods (Brown & Harris, 2012).

In contrast, food pickiness is defined as the rejection of a substantial number of familiar including already tasted foods, because of their taste or texture (Taylor et al., 2015). It also involves the consumption of inadequately small amounts of foods or can occur after effective tasting. Picky eating is associated with sorting mixed foods, in-depth examination of foods, long chewing time, refusing to open the mouth (Williams et al., 2005). In sum, although food neophobia and pickiness seem to be characterized by different prototypes, the distinction between the two constructs can be fuzzy, as they are strongly correlated (e.g., Rioux et al., 2017; Smith et al., 2017). Some authors go as far as to claim that they are different symptoms of the same entity (e.g., Dovey et al., 2008). In any case, beyond the fact that they share symptoms such as a limited food repertoire or disruptive mealtime behaviors (e.g., tantrums), they both must involve rigid patterns of eating, rigid food repertoire always served with the same trimmings, and the presence of strong consumption rituals (Carruth et al., 1998), which are reminiscent of a lack of cognitive flexibility.

Before we come to our hypothesis, it is necessary to briefly summarize the available explanations of neophobia and pickiness. They fall into two broad general categories, innate and environmental influences. Estimations from twin studies (for a review see Cooke, 2018) suggest that food neophobia has a heritability between 58% and 78% (Cooke et al., 2007; Fildes et al., 2016), and food pickiness has a heritability of around 46% (Smith et al., 2017). Food rejection has also been associated with several temperamental traits (Lafraire, Rioux, Giboreau, et al., 2016; Nicklaus & Monnery-Patris, 2018). Environmental evidence comes from studies on early exposure (i.e., early food experience and family feeding practices) or that some food practices have a negative impact on children's food rejection (see DeCosta et al., 2017; Nicklaus & Monnery-Patris, 2018). In sum, if both innate and environmental factors play an important role in children's development of food rejection, it remains unclear how these two general explanatory factors might be translated into psychological factors or with which cognitive factors they might be correlated. Thus, there is a need for investigating explanatory cognitive processes underpinning food rejection behaviors.

One candidate among cognitive factors is conceptual knowledge that can influence food-based reasoning (Lafraire, Rioux, Giboreau, et al., 2016). Recent studies have shown that children's food rejection is inversely related to their categorization scores of discriminating vegetables and fruits (Rioux et al., 2016), their conceptual knowledge about contextual (thematic) information (Pickard et al., 2021a), or to their conceptual inferences about food properties (Rioux et al., 2018a) or food effects on health (Foinant et al. 2021). However, these categorization difficulties can be associated with food neophobia but not pickiness or the reverse (e.g., Foinant et al., 2021; Rioux et al., 2018b, or Pickard et al., 2021b). However, this evidence might also be interpreted as difficulties to flexibly process and use conceptual information about unusual experimental situations. Recent evidence (Pickard et al., 2021b) revealed, in a forced-choice task, that more neophobic children were less able to recategorize a food from another point of view after the first categorization than less neophobic children.

Interestingly, there was no effect of food rejection on the performance in the first categorization trial which is not predicted by a “different knowledge” hypothesis. Altogether these results are consistent with a role for executive functions, which we now develop.

As mentioned above, most of the behavioral descriptions of neophobia and pickiness mention rigid eating behaviors and categorization difficulties that might be described as a lack of cognitive flexibility or as difficulties to inhibit former representations of the same foods, or former contexts of presentations, or former routines of consumptions. Relations between executive function and food rejection have never been directly assessed so far. Here, we will refer to Miyake’s model of executive functions which distinguishes three components, working memory, inhibition, and cognitive flexibility (Miyake et al., 2000). Indeed, neophobic children refusing to taste novel foods, seeking, rather, foods they are already familiar with (Pliner & Hobden, 1992). As for picky children, they may fail to inhibit or shift their attention away from differences in the food experience (e.g., taste, dish composition, or cooking process).

One further reason to look at executive functions is that food rejection has been suggested to be a risk factor for developing eating health-related problems. Thus, it is crucial to find common profiles between early food rejection and later health problems. In this respect, obesity or anorexia nervosa have been associated with poorer performance in executive functions tasks. For instance, obesity has been found to be correlated with impaired working memory (Maayan et al., 2011; Wu et al., 2017; but see Cserjési et al., 2007 and Verdejo-García et al., 2010 who produced null findings), inhibition (Groppe & Elsner, 2015; Rollins et al., 2014), and cognitive flexibility (Cserjési et al., 2007; Delgado-Rico et al., 2012; Verdejo-García et al., 2010) as compared to healthy controls. Verdejo-Garcia et al.’ study (2010) showed that cognitive flexibility (measured by the Trail-making test) was the executive function most significantly affected in overweight children. To date, there are no indications of lower performance in working memory and inhibition in anorexia nervosa (Rose et al., 2012; Seidel et al., 2021; Stedal et al., 2012). Conversely, a review of 15 studies has shown that performance in cognitive flexibility is consistently found to be lower in anorexia nervosa patients than in healthy individuals (Roberts et al., 2007). Furthermore, Stedal et al. (2012) show that at 9 years of age, children with anorexia nervosa do not have specific difficulties on executive functions tasks, except cognitive flexibility. Of note, anorexia nervosa patients have been found to obtain better performance than healthy control on vocabulary tests (Stedal et al., 2012, 2013). In sum, there is evidence showing that eating health-related problems might be associated with executive functions, in particular cognitive flexibility. Establishing that weaker executive functions also characterize early food-related conditions which are hypothesized to predict later eating health-related problems is a major research question.

The present study examined associations among 3-to-6-years old children's food neophobia and pickiness and their performance on working memory, inhibition, and cognitive flexibility tasks. We also tested children's vocabulary to disambiguate the relative contribution of general knowledge versus cognitive factors. Indeed, as shown above, there is also evidence that food-related knowledge might be impaired in children with high levels of food rejection. Thus, it is important to assess whether these results might be explained by differences in world knowledge or by cognitive processes such as executive functions. In the present paper, we also assess whether neophobia and pickiness are associated with the same executive functions. Depending on the results, the "single" condition or the "dissociated" condition will be strengthened.

7.2. Methods

7.2.1. Participants

Two hundred and sixty-eight (268) children aged 3–6 years were recruited from preschools. Participants were excluded if they did not complete all the cognitive assessment tasks (n = 28). This left a final sample of 240 children (128 girls; age range = 46.5 to 76.0 months; mean age = 60.6 months; SD = 7.89). They were predominantly Caucasian and came from middle-class urban areas. Informed consent was obtained from their school and their parents. The procedure was in accordance with the Declaration of Helsinki and followed institutional ethics board guidelines for research on humans.

In order to assess each child's food rejection dispositions, caregivers filled out the Child Food Rejection Scale (CFRS; Rioux et al., 2017). The CFRS was developed to assess, by hetero-evaluation, 2-to-7-year-old children's food rejection on two subscales, one subscale assessing food neophobia (6 items), the other assessing pickiness (5 items). On a 5-point Likert-like (*Strongly disagree*, *Disagree*, *Neither agree nor disagree*, *Agree*, *Strongly agree*), caregivers were asked to rate 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*"). Each answer was then numerically coded with high scores indicating higher food neophobia and pickiness (scores could range from 6 to 30 for neophobia, M = 14.9, SD = 5.25; from 5 to 25 for pickiness, M = 16.6, SD = 4.90; and global food rejection from 11 to 55, M = 31.5, SD = 9.16).

7.2.2. Procedure

Children were tested individually on the cognitive assessment tasks in two different sessions of twenty minutes each, two tasks at a time. The order of the tasks was random. We assessed world knowledge via a standard vocabulary test. In this approach, scholars argue that a broader vocabulary is a good proxy to better world knowledge. We also assessed the three components of executive functions described by Miyake et al. (2000), updating in working memory, flexibility, and inhibition. For the working memory and the flexibility tasks, we adapted the corresponding tasks from the National Institutes of Health Toolbox battery (NIH Toolbox CB). We followed the same protocol except that we implemented the tasks on Open Sesame and the instructions were given in French. We assessed participants' skills with a touch screen computer.

7.2.2.1. Working memory

The List Sorting Working Memory assesses children's working memory as part of the NIH Toolbox Cognition Battery (Tulsky et al., 2014). It is a computerized sequencing task requiring sorting and sequence stimuli that are presented visually and auditorily. Children are presented with a sequence of colored pictures depicting an item (e.g., an animal) along with their auditory name (e.g., "Lion"). Each item was displayed for 2 seconds. At the end of each sequence, they were instructed to verbally recall all the items, from the smallest animal to the biggest one. The test starts with a list of two items and stops when the participant makes errors for two consecutive, same-length trials. After this "1-list" version, children are presented with a "2-list" version with two kinds of stimuli (i.e., animals and food pictures). In this version, children were requested to organize stimuli from one category (i.e., food), from the smallest to biggest, and then to do the same for the other category (i.e., animals). The maximum score is 16.

7.2.2.2. Cognitive flexibility

The Dimensional Change Card Sort is a rule-shifting task that assessing children's cognitive flexibility which has been adapted from the NIH Toolbox Cognition Battery (DCCS; Zelazo et al., 2013). Basically, it assesses cognitive flexibility, comparing children's performance in different types of trials, involving (or not) rule switching. Children are shown two target stimuli (e.g., a blue rabbit and a red boat) and asked to sort a series of test stimuli (e.g., red rabbits and blue boats), first according to one dimension (e.g., color), and then according to the other (e.g., shape). The task was composed of four phases: familiarization, pre-switch, post-switch, and mixed. In the familiarization phase, the experimenter explains two rule games, the shape or the color game (four trials with feedback). In the pre-switch phase, one rule (e.g., color) was used for five trials and is followed by the second rule in the post-switch phase (five trials). Finally, the mixed-phase consisted of 30 trials, including 24 "frequent" (e.g., color) and 6 "infrequent" (e.g., shape) trials presented in a pseudorandom order (with two to five frequent trials preceding each infrequent trial). The flexibility score was calculated according to the NIH scale (Zelazo et al., 2013) and was based on accuracy. It also included reaction times for participants with an accuracy equal to or beyond 80%.

7.2.2.3. Inhibition

We used a computerized version of the Real Animal Size Test (RAST; Catale & Meulemans, 2009) which was designed to assess children's inhibition capacities. The RAST is a nonalphabetic Stroop-like task. Children are asked to categorize pictures of animals on the basis of their real (world) size, either small (i.e., a butterfly and a bird) or big (i.e., an elephant and a horse). The test contrasts congruent and incongruent trials, the latter being that the picture size and the animal size are incongruent (e.g., a small picture of an elephant and a big picture of a butterfly). The task is composed of three phases: the training phase followed by control and test trials. Before the beginning of the task, we ensure that children knew the four animals and were able to say that the horse and the elephant are big animals whereas the butterfly and the bird are small animals. The control, no interference, phase was composed of twelve trials, with all animals displayed with the same medium size. This phase was followed by a training phase in which children were informed that the size of the image would change across stimuli. They were told that no matter the size of the image, they would have to say whether the animal is big or a small "in real life". Feedbacks were provided after every trial. The test phase was composed of big and small animals, with congruent trials and incongruent trials. Thus, incongruent trials elicited interference related to the picture size since participants had to inhibit the pictorial size and to give a response according to the real animal's size. Finally, the test phase was composed of thirty-two trials (four animals presented with the two sizes, four times each) were performed by the children, and feedback was no longer provided. The interference score is the difference between the average RT for the congruent trials (M = 1481, SD = 404) and the average RT for the incongruent trials (M = 1518, SD = 450). Higher difference scores indicate better inhibition capacities, whilst lower scores indicate poorer inhibition.

7.2.2.4. World knowledge

For the vocabulary test, we used the EVIP which is a French version (Canadian norms) of the PPVT (Peabody Picture Vocabulary Test, Dunn & Dunn, 2007). In this test, children had to select one out of four images associated with a noun given by the experimenter. Responses were recorded on a paper sheet and a standard score was computed according to the age.

7.2. Data analysis

Preliminary Spearman's correlations tested significant associations between children's age and the study's main variables (children's food rejection scores and cognitive assessment scores). Children's age was significantly related to several cognitive scores and food neophobia. Significant positive correlations were found between children's age and scores on the three EF tasks, List Sorting (*rho* = .219, p <.001), RAST (*rho* = .251, p <.001), and DCCS (*rho* = .300, p <.001). A negative correlation was found with food neophobia (*rho* = -.157, p =.015), but not with pickiness (*rho* = -.059, p =.360) and the global food rejection (*rho* = -.105, p = .103). In addition, independent t-tests examined differences in children's age, food rejection, and cognitive assessment scores for girls and boys. We also tested gender effects and t-tests did not reveal any differences between girls and boys on any of these measurements (p > .05).

In view of these preliminary analyses, general linear models were used to calculate the coefficient estimate (β) controlling for children's age. Predictors were kept in the adjusted models following their ability to improve the model through the goodness of fit assessed using the Akaike Information Criterion (AIC; Hu, 2007). The model that showed the better AIC was used in adjusted models presented in the main results.

Descriptive statistics for the children in this study can be seen in Table 3.

	Children (n = 240) Mean (*SD*)
Age (in months)	60.6 (7.89)
Global food rejection	31.5 (9.16)
Food neophobia	14.9 (5.25)
Food pickiness	16.6 (4.90)
EVIP	116 (19.9)
List Sorting	5.92 (2.25)
RAST	-37.0 (264)
DCCS	4.64 (1.23)

Table 3. Descriptive statistics for age, food rejection scores, and cognitive assessment scores. *SD*: standard deviation

Associations among children's food rejection scores, world knowledge, and executive functions, after controlling for children's age, can be seen in Table 4.

	Global food rejection	Food neophobia	Food pickiness	World knowledge	Working memory	Inhibition	Cognitive flexibility
Global food rejection		*r* = .908 *p* < .001	*r* = .876 *p* < .001	*r* = -.042 *p* = .518	*r* = -.054 *p* = .403	*r* = -.165 *p* = .011	*r* = -.280 *p* < .001
Food neophobia	*r* = .908 *p* < .001		*r* = .611 *p* < .001	*r* = -.129 *p* = .046	*r* = -.105 *p* = .105	*r* = -.131 *p* = .042	*r* = -.301 *p* < .001
Food pickiness	*r* = .876 *p* < .001	*r* = .611 *p* < .001		*r* = .087 *p* = .181	*r* = .010 *p* = .876	*r* = -.166 *p* = .010	*r* = -.180 *p* = .005
World knowledge	*r* = -.042 *p* = .518	*r* = -.129 *p* = .046	*r* = .087 *p* = .181		*r* = .369 *p* < .001	*r* = .036 *p* = .581	*r* = .346 *p* < .001
Working memory	*r* = -.054 *p* = .403	*r* = -.105 *p* = .105	*r* = .010 *p* = .876	*r* = .369 *p* < .001		*r* = -.049 *p* = .449	*r* = .263 *p* < .001
Inhibition	*r* = -.165 *p* = .011	*r* = -.131 *p* = .042	*r* = -.166 *p* = .010	*r* = .036 *p* = .581	*r* = -.049 *p* = .449		*r* = .053 *p* = .414
Cognitive flexibility	*r* = -.280 *p* < .001	*r* = -.301 *p* < .001	*r* = -.180 *p* = .005	*r* = .346 *p* < .001	*r* = .263 *p* < .001	*r* = .053 *p* = .414	

Table 4. Spearman correlation coefficients, controlling for children age, among children's food rejection scores, world knowledge, and the executive functions scores.

7.3. Results

Table 5 shows the adjusted models using children's global food rejection, food neophobia, and pickiness scores as the outcomes and cognitive assessment tasks as predictors. After adjusting for covariates, we found that children's food global rejection, food neophobia, and pickiness scores were negatively associated with cognitive flexibility ($p < .05$). Global food rejection and food pickiness scores were negatively associated with inhibition ($p < .05$). Only food pickiness scores were positively associated with general world knowledge ($p < .05$).

Outcomes	Predictors	*β*	*t*	AIC	R^2	*p*
Global food rejection	DCCS +	-.306	-4.98	1727	.089	<.001
	RAST	-.135	-2.19	1724	.107	.030
Food neophobia	DCCS	-.337	-5.52	1453	.113	<.001
Food pickiness	DCCS +	-.253	-3.81	1439	.039	<.001
	EVIP +	.147	2.21	1436	.057	.028
	RAST	-.129	-2.06	1434	.074	.041

Table 5. Generalized linear model using children's global food rejection, food neophobia, and pickiness scores as the outcome and cognitive assessment tasks as predictors. Only adjusted models showing a better fit to the data through the AIC are presented.

There were significant relationships between both food rejection scores (i.e., food neophobia and pickiness) and cognitive flexibility. We used the *linearhypothesis* function from the *car* package in R (Fox & Weisberg, 2019) to test the linear hypothesis that the difference between the regression coefficients of food neophobia and pickiness for explaining cognitive flexibility differed from 0. Results revealed that food neophobia was a stronger predictor of cognitive flexibility than food pickiness (t = -2.57, p = .011).

7.4. Discussion

The present study sought for associations between early food rejection dispositions (i.e., food neophobia and pickiness) and cognitive factors (i.e., executive functions and world knowledge). To the best of our knowledge, this paper is the first to establish a strong influence of cognitive flexibility, and that neophobic and picky children have different cognitive profiles. These results are important because they are the first that connect food rejection with underlying intermediary cognitive monitoring processes. Indeed, most food rejection explanations refer to broad influences such as environmental and innate factors, which leave decision-making mechanisms unspecified. However, ingesting or not are behavioral decisions involving cognitive mechanisms. Recent evidence has revealed that children with food rejection had poorer categorization abilities compared to the other children, a cognitive difference that is compatible with executive difficulties. Our results clearly show that cognitive flexibility is a potential explanatory factor for both neophobia and pickiness. They are compatible with the two general categories of explanations, environmental and innate. They complement them in two senses. The first, maybe trivial, is that executive functions are also under genetic and environmental influences (Barkley, 2012; Friedman et al., 2008; Li et al., 2015). The much less trivial question is whether common genetic and environmental influences might influence both executive functions and food rejection or the last through the first.

A related point was the association between food neophobia/pickiness and later eating health-related problems (i.e., obesity and anorexia nervosa). Given that children's executive functions have been shown to be relatively stable (Miyake & Friedman, 2012) over time, these early characterizations of food rejection might predict or are compatible with later eating health-related problems especially those that have been characterized by executive functions difficulties. Future work should contribute to establishing if children with low executive functions performance and high food rejection are more at risk of later health difficulties.

The study was also meant to differentiate neophobia from pickiness. Even though typical behavioral manifestations of these two food rejection types may differ, our introduction suggested that there is overlap between the two. The hypothesis was that cognitive factors such as executive functions would contribute to differentiate them. Results show that although cognitive flexibility explained both rejection types, it was the only factor correlating with neophobia and it was a stronger predictor of neophobia than of pickiness. Thus, the key factor in neophobia is flexibility, not inhibition. This important result suggests that neophobic children are unable to flexibly represent the novel food, for example in a way that would allow them to accept them. Thus, the inhibition of irrelevant information does not play a crucial role, but, rather, the possibility to give information a new interpretation in the context (see Pickard et al., 2021b).

Picky eaters on the other side seem to be a fuzzier entity, with inhibition, cognitive flexibility, and world knowledge playing a role. Picky eaters have a narrow repertoire of preferred foods, sometimes refusing to retry a food previously disliked (Dovey et al., 2008; Taylor et al., 2015) but who also accept to taste small portions of foods. This is compatible with the observation that inhibition is negatively correlated with children's willingness to eat a disliked food (Rigal et al., 2016). Their cognitive pattern is compatible with a more diverse attitude towards foods.

Picky children lack both inhibitory and flexibility skills. They might be unable to inhibit a previous negative hedonic experience (which makes much less sense for neophobic children who do not taste novel foods) which might also be due to an inability to flexibly redescribe novel foods or previous negative experience, which is the defining feature of cognitive flexibility. This general ambivalent attitude might explain the unexpected positive association between food pickiness and general world knowledge. To be picky, it is important to encode them very distinctively so that, later, children recognize them. Interestingly, these subtle judgments would be impossible with a looser encoding. This is compatible with the observation that picky eaters refuse foods that differ only slightly from the usual, prototypical, appearance of an accepted food.

Thus, neophobia is a very specific difficulty to flexibly encode novel foods, especially when they have to be cross-classified. This is compatible with the fact that food neophobia was found to be a stronger predictor than pickiness for conceptual understanding is enlightening (e.g., Pickard et al., 2021b; Rioux et al., 2018). Neophobic children had more difficulties than picky children in identifying a targeted conceptual relation or generalizing the properties of a food to other foods. Such difficulties may be related to underdeveloped cognitive flexibility. On the other, the lack of flexibility also encountered in picky children might also be compensated by better world knowledge which would explain the lack of association between food pickiness and conceptual tasks.

This study highlights important associations between children’s food rejection dispositions (i.e., food neophobia and pickiness) and their executive functions. Future work should include executive functions tests, including those assessing the emotional dimension (“hot”; Zelazo &

Carlson, 2012) of executive functions. It also calls for further investigation aiming to disambiguate the interplays among food rejection, executive functions, and categorization abilities.

Chapter 8. Executive functions mediate the relation between food rejection and categorization

The results of the previous chapter revealed that higher levels of food rejection were associated with poorer executive functions. More precisely, neophobic children were cognitively more rigid than neophilic children, whereas picky children lacked inhibition compared to non-picky children.

This chapter presents two experiments, designed to test whether higher levels of food rejection may lead to a decrease in categorization abilities through a mediating effect of a decrease in executive functions.

Experiment 1, an adaptation of Rioux et al.'s (2016) pivotal study extended with measures of executive functions, was a forced-choice superordinate categorization task in which 137 children had to discriminate vegetables from other kinds of stimuli (i.e., fruits and thematically related utensils). Results revealed that children's cognitive flexibility scores partly mediated the relationship between food neophobia and categorization performance.

Since cognitive flexibility involves switching between alternative conceptual dimensions when appropriate, one consequence of a lack of cognitive flexibility is that neophobic children might be less able to flexibly recategorize foods when needed, or be unable to see them under different category standpoints.

In Experiment 2, we asked 100 children to alternatively associate the same food with two exemplars from taxonomic and thematic categories while ignoring an unrelated food choice. The double selections of correct choices assumes categorical flexibility and should test whether neophobic children have difficulties accessing an alternative form of categorization conflicting with a previous form of categorization. Results confirmed the role of cognitive flexibility as a mediator of the relationship between food neophobia and double selections performance.

8.1. Introduction

A lack of dietary variety in childhood leads to enduring impacts on both physical and cognitive health (Evans et al., 2018). The two strongest obstacles to dietary variety, in particular in extending young children's intake of fruit and vegetables, are food neophobia and pickiness assumed to be the two main kinds of food rejection (Birch & Fisher, 1998; Dovey et al., 2008; Lafraire, Rioux, Giboreau, et al., 2016). In the present study, we focus on general cognitive factors that are associated with food neophobia and pickiness.

Food neophobia is the reluctance to eat or even try novel food (Pliner & Hobden, 1992). Heavily interlinked to food neophobia, yet distinct, food pickiness is defined as the rejection of a substantial number of familiar foods (Taylor et al., 2015). Whereas a neophobic reaction occurs before the tasting step, a rejection understood as pickiness may occur after the tasting step (Dovey et al., 2008). The two food rejection dispositions are expressed by many typically developing children (Moding & Stifter, 2018; Rioux et al., 2017a). However, problems arise when children present extreme forms of food rejection leading to problematic eating behaviors (Johnson et al., 2018). For instance, neophobic children may rigidly refuse to expand their food repertoire with novel fruits or vegetables (Carruth et al., 2004). Picky eaters may reject a previously accepted food because it is not prepared in the same manner (Carruth et al., 1998). In both cases, food rejection is often associated with challenging disruptive behaviors (e.g., tantrums) that contribute to discouraging caregivers to introduce variety in meal preparations (Carruth et al., 1998; Johnson et al., 2018; Williams et al., 2005). In sum, when severe, food rejection can have negative consequences for health by suppressing dietary variety needed for normal and healthy development (Nicklaus, 2009; Nyaradi et al., 2013). It is therefore of critical importance to investigate the psychological underpinnings of food neophobia and pickiness, particularly if we are to construct effective interventions for increasing the consumption of fruits and vegetables during this critical developmental stage. In the current study, we examine potential cognitive mechanisms underlying food rejection dispositions which might also interact with other cognitive abilities such as categorization.

A recent review pointed out that many factors are involved in children's acceptance or rejection of food, including genetic and environmental influences, but also categorization abilities (Lafraire et al., 2016). Some researchers suggest that the development of categorization abilities in the food domain is inversely related to food rejection, abilities that largely improve around 2-3 years of age when children begin to exert greater selectivity on their diet (Dovey et al., 2008; Harris, 2018; Lafraire, Rioux, Giboreau, et al., 2016; Rioux et al., 2016). Accordingly, acceptance depends upon children's ability to recognize and categorize a given food. Food categorization can take several forms, (a) taxonomic, deciding whether an object is a food or not; whether a food is a vegetable or a fruit, (b) thematic, whether some foods are eaten together or not, (c) health, whether it is healthy or unhealthy, etc. (Nguyen & Murphy, 2003). Categorization abilities allow children to build rich and generalizable conceptual knowledge in the food domain. For instance, understanding that carrots are edible allows children to extend that knowledge to novel carrots they encounter (even if those carrots vary in shape, color, or size; Murphy, 2002). However, if children have limited categorization abilities, when they encounter a novel kind of carrot, purple for instance, they might not be able to categorize it as a carrot, and they will be unable to infer some properties of the carrot category (e.g., that it is sweet, rich in vitamins, edible, etc.). Children who fail to categorize a given food are more likely to reject it (Rioux, 2020; Rioux et al., 2017b). Thus, it has recently been proposed that children with high levels of food rejection may lack the categorization abilities that would allow them to form inclusive and generalized categories in the food domain (Harris, 2018).

This hypothesis recently received empirical support. In their series of studies, Rioux et al. (2016; 2017b; 2018a; 2018b) found a negative correlation between food rejection and food categories-based abilities (e.g., categorization and inductive performance). Initially, they tested 118 2- to 6-year-old children in a forced-choice task in which they were asked to discriminate two superordinate categories, vegetables and fruits (Rioux et al., 2016). Higher levels of food rejection predicted lower performance on the task (see also Foinant et al., 2021a and Rioux et al., 2018b for similar results on taxonomic forced sorting tasks). Later studies also revealed that food rejection was inversely related to taxonomic category-based induction performance (Rioux et al., 2017b; 2018b). The negative relationship between food rejection and categorization abilities is not restricted to taxonomic categories but also extends to thematic categories (Pickard et al., 2021a). Using a proportional (A:B::C:?; see also Thibaut et al., 2010 for a similar paradigm) analogy task, Pickard et al. (2021a) observed that when presented with a thematic food base pair (A:B; ice cream:wafer cone) the more neophobic and pickier children failed more often to correctly extend this relation to the thematic match of the target C (C:?; burger:burger bun or chicken) than their more neophilic and less picky counterparts. Furthermore, several studies have found food rejection and category-based induction performance to be significantly negatively correlated (Foinant et al., 2021b; Rioux et al., 2017b; 2018b). For instance, whereas the more neophilic and less picky children referred to category membership when generalizing blank properties (e.g., "contains zuline") of a given food to another food (e.g., from a green zucchini to an orange carrot), the more neophobic and pickier children tended to generalize properties based on color similarity (e.g., from a green zucchini to a green banana; Rioux et al., 2017b).

It has been suggested that children with high rejection tend to generalize properties from one food to another based on perceptual cues rather than taxonomic membership because of their poor knowledge about food relations (Rioux et al., 2017b). In the current study, we propose the alternative hypothesis that neophobic and picky children’s low performance on categorization tasks is due to underdeveloped executive functions. Executive functions refer to processes involved in the control of action and thought, such as working memory, inhibition, and cognitive flexibility (Miyake et al., 2000). Recent evidence has shown that food rejection was negatively associated with inhibition and cognitive flexibility in young children (Foinant et al., *submitted*). More precisely, cognitive flexibility was the executive function most significantly affected in neophobic and picky children.

However, developed cognitive flexibility is required for children to be able to identify the conceptually relevant dimensions, to ignore more salient but conceptually irrelevant dimensions, and finally, to select the appropriate conceptual representation (Blaye & Jacques, 2009; Lagarrigue & Thibaut, 2020). For instance, Blaye and Jacques (2009) showed that the development of categorization abilities is based on both knowledge and cognitive flexibility. The authors tested 3-, 4-, and 5-year-old children on a flexible categorization task, where they were required to associate a target stimulus (e.g., a dog) with both a taxonomic associate (i.e., a snail) and a thematic associate (i.e., a kennel), while ignoring an unrelated stimulus (i.e., a phone). This flexible categorization task implies that children had to first select between two conflicting but correct choices and immediately switch to a new form of categorization. The authors observed that if the three age groups had above-chance performance to alternatively select the two correct choices, rapid change in categorical flexibility occurs between 4 and 5 years. They concluded that this period coincides well with the rapid change observed on the Dimensional Chand Card Sort (DCCS; Diamond, 2013; Zelazo et al., 2013). Supporting this conclusion, a recent study witnessed a positive correlation between young children’s performance on the DCCS and their categorization abilities (Lagarrigue & Thibaut, 2020).

8.2. The current research

In line with existing findings, the present research hypothesized that cognitive flexibility might be involved, directly, or as a mediating factor in the relation between food rejection and categorization.

We test this hypothesis in two experiments. The first experiment builds on Rioux and colleagues' task (2016) which established the relationship between children's food rejection and categorization abilities and extend it with measures of executive functions. It is a forced-choice superordinate categorization task in which children had to discriminate vegetables from other kinds of stimuli (i.e., fruits and thematically related utensils). Since cognitive flexibility involves switching between alternative conceptual dimensions when appropriate, one consequence of a lack of cognitive flexibility is that neophobic and picky children might be less able to flexibly recategorize foods when needed, or be unable to see them under different category standpoints. Therefore, in a second experiment, we asked children to alternatively associate the same food with two exemplars from taxonomic and thematic categories while ignoring an unrelated food choice.

To measure children's cognitive flexibility, we used the DCCS (Zelazo et al., 2013). We also collected measures of children's inhibition and working memory to control for a specific effect of cognitive flexibility. Indeed, both executive functions had previously been associated with categorization abilities (Rabi & Minda, 2014; Snape & Krott, 2018). The measures have been respectively collected using a picture-based Stroop task, the Real Animal Size Test (RAST; Catale & Meulemans, 2009) and, a visual and auditory memory task, the List Sorting task (Tulsky et al., 2014). Furthermore, we tested children on a vocabulary test, reflecting world knowledge. Vocabulary develops concurrently with executive functions and there is a strong association between the two during the preschool years (Gooch et al., 2016; Weiland et al., 2014). It has also been argued that world knowledge is a key factor for conceptual abstraction and understanding in the sense that the more children know about the world, the more likely they will discover conceptually relevant dimensions (Gentner & Hoyos, 2017). A positive association with vocabulary and categorization abilities may thus be interpreted as a sign that children used their background knowledge to make sense of the contextual demands of the tasks at hand.

Our main hypotheses are as follows:

H1. Levels of food rejection are negatively associated with performance on the categorization tasks.

H2 Levels of food rejection are negatively associated with performance on the executive functions tasks. More precisely, neophobic and picky children have poorer cognitive flexibility performance than their neophilic and less picky counterparts.

H3. Children's executive functions mediate the relationship between food rejection and categorization performance. Higher levels of food rejection lead to a decrease in categorization performances through a mediating effect of a decrease in cognitive flexibility.

8.3. Experiment 1: Superordinate categorization task

Recent evidence has found that young children's food rejection was negatively associated with cognitive flexibility (Foinant et al., *submitted*). As mentioned above, cognitive flexibility is an important executive function involved in categorization abilities (Blaye & Jacques, 2009; Lagarrigue & Thibaut, 2020). In light of those findings, our central hypothesis is that undeveloped cognitive flexibility might explain former poor categorization results in children with high levels of food rejection (e.g., Rioux et al., 2016).

To investigate the potential mediating role of cognitive flexibility on the relationship between food rejection and categorization abilities, we tested 4-to-6-year-old children on a forced-choice superordinate categorization task in which they had to discriminate vegetables from other kinds of stimuli (i.e., fruits and thematically related utensils). In order to test this association, we capitalized on a task by Rioux and colleagues' task (2016) who found a correlation between children's food rejection scores and categorization abilities, with two important changes, control trials and stimulus identification (see methods).

8.3.1. Participants

One hundred and thirty-six (136) children aged 4-6 years were recruited from preschools. Participants were excluded when they did not complete all the cognitive assessment tasks (n = 14). This left a final sample of 122 children (67 girls; age range = 57.0 to 75.1 months; mean age = 67.4 months; SD = 4.05). They were predominantly Caucasian and came from middle-class urban areas. Informed consent was obtained from their school and their parents. The procedure was in accordance with the Declaration of Helsinki and followed institutional ethics board guidelines for research on humans.

8.3.2. Materials – categorization task

To assess each child's food rejection dispositions, caregivers filled out the CFRS (Rioux et al., 2017b). The CFRS is a hetero-evaluation scale measuring 2-to-7-year-old children's food rejection on two subscales: one is measuring children's food neophobia (6 items) and one is measuring their pickiness (5 items). On a 5-point Likert-like (*Strongly disagree*, *Disagree*, *Neither agree nor disagree*, *Agree*, *Strongly agree*), caregivers were asked to rate 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*"). Higher scores indicate higher levels of food neophobia and pickiness (scores could range from 6 to 30 for neophobia, *M* = 15.2, *SD* = 4.89; from 5 to 25 for pickiness, *M* = 16.2, *SD* = 4.34; and global food rejection from 11 to 55, *M* = 31.4, *SD* = 8.31).

Children were tested with a set of 34 color photographs from two categories: vegetables (*n* = 16) and others (*n* = 18, 10 fruits, and 8 utensils). The set of 'others' stimuli was composed of items coming from a taxonomical category close to vegetables, i.e., fruits, and items from a semantically related category, i.e., utensils. The utensils were meant to be control stimuli. We chose kitchen utensils as controls because, despite the fact they are clear nonfoods, they are semantically related to the food domain. Children who miscategorized 2 or more utensils as vegetables were excluded (*n* = 0). Each picture was printed on a laminated card measuring 14.8 cm x 21 cm (see Figure 10 for an example of the stimuli used in the experiment). See Appendix 5 for the full list of stimuli.

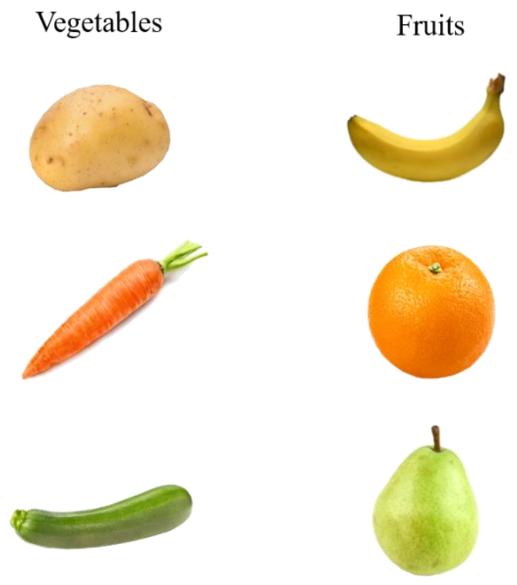

Figure 10. Example of the stimuli used in experiment 1.

8.3.3. Procedure categorization

Children were tested individually in their preschool. They sat at a table, with the experimenter on their side. There were two parts to the categorization task, run in a fixed order (forced-choice task then naming task) in the same session for all the children.

8.3.3.1. Categorization task – forced-choice task

On the table, there were two mailboxes. The experimenter explained to the child that the rule of the game was to sort the pictures into the two mailboxes. Opaque mailboxes were favored to prevent children to use comparison strategies. First, the children realized a training of 16 demonstration trials and were told, "I'm going to show you pictures of different things. I want you to help me put the animal pictures (n = 8) all in the same box, and put the other pictures, that are not animals (tools, n = 6, and flowers, n = 2) in the other box". During the training, the experimenter provided feedbacks to the children. Following the training, the children were told, "Now, I want you to help me put the pictures of the vegetables all in the same box, and put the other pictures, that are not vegetables in the other box". Feedbacks were no longer provided. The order in which the photographs were presented was randomized for each participant. For each item, a score of 1 was given when children successfully placed it in the corresponding mailbox, and a score of 0 was given when they did not place it properly.

8.3.3.2. Control task – Naming task

The last part of the categorization task was a control naming task which was also used to assess the relationship between food lexical knowledge and the food categorization task. Children were shown all the food pictures from the sorting task, one by one in a randomized order. For each item, the naming was scored 1 when correct or synonymous, and 0 for incorrect names or unable to provide an answer.

8.3.4. Procedure cognitive assessment tasks

Children were tested individually on the cognitive assessment tasks in two different sessions of twenty minutes each, two tasks at a time. The order of the tasks was random. We assessed world knowledge via a standard vocabulary test and the three components of executive functions described by Miyake et al. (2000) that are working memory, flexibility, and inhibition. For the working memory and the flexibility tasks, we adapted the corresponding tasks from the National Institutes of Health Toolbox battery (NIH Toolbox CB). We followed the same protocol except that we implemented the tasks on Open Sesame and the instructions were given in French. We assessed participants' skills with a touch screen computer.

8.3.4.1. Working memory

The List Sorting Working Memory was designed to assess children's working memory as part of the NIH Toolbox Cognition Battery (Tulsky et al., 2014). The List Sorting is a sequencing task requiring sorting and sequence stimuli that are presented visually and auditorily. Children were presented on a computer with a sequence of colored pictures depicting an item (e.g., an animal) along with their auditory name (e.g., "Lion"). Each item was displayed for 2 seconds. At the end of each sequence, they were instructed to remember and to verbally recite all the items from the smallest stimulus to the biggest. The number of items in the list started from two and increased every two trials to progressively tax the working memory. The task was stopped after two errors in two consecutive trials with the same number of items. After this "1-list" version, children were presented with a "2-list" version in which two kinds of stimuli were presented (i.e., animals and food pictures). In this version, children were inquired to organize stimuli from one category (i.e., food), from smallest to biggest, and then from the other category (i.e., animals), also from smallest to biggest. A score of 1 was given when children were successful on a trial, and a score of 0 when they were not successful on recalling in the expected order all the images in a trial.

8.3.4.2. Cognitive flexibility

The DCCS was designed to assess children's cognitive flexibility as part of the NIH Toolbox Cognition Battery (Zelazo et al., 2013). The DCCS is a rule shifting task in which children are shown two target stimuli (e.g., a blue rabbit and a red boat) and asked to sort a series of bivalent test stimuli (e.g., red rabbits and blue boats) first according to one dimension (e.g., color), and then according to the other (e.g., shape). The task was composed of four phases: familiarization, pre-switch, post-switch, and mixed. The goal of the familiarization phase was to ensure that children understood clearly the shape or the color game. In total, four trials (two color and two shape trials) were performed during which we provided children with feedbacks. For the pre-switch phase, one rule (e.g., color) was used for five trials, and for the post-switch phase, the other rule (e.g., shape) was also presented for five trials. Children were explicitly informed to switch during the transition between the two phases. Children were given feedbacks after each trial. Finally, the mixed-phase consisted of 30 trials, including 24 "frequent" (e.g., color) and 6 "infrequent" (e.g., shape) trials presented in a pseudorandom order (with two to five frequent trials preceding each infrequent trial). In this phase, no feedbacks were given. All the RT inferior to 100ms and superior to 10000ms or two deviation standards away from the mean were considered as outliers and discarded from the analysis. The flexibility score was calculated following the NIH quotation (Zelazo et al., 2013; 2014), using a two-vector method that incorporated both accuracy and reaction time, for participants who achieved the accuracy criterion of 80% or better.

8.3.4.3. Inhibition

The Real Animal Size Test (RAST; Catale & Meulemans, 2009) was designed to assess children's inhibition. The RAST is an analphabetic Stroop task requiring to answer on the real size of animal pictures, either small (i.e., a butterfly and a bird) or big (i.e., an elephant and a horse), despite trials when the animals are displayed in incongruent size (e.g., a small elephant or a big butterfly). The task was composed of three phases: control, training, and test. In each phase, children were presented with an animal picture on the computer screen and were asked to press one button for big animals and another button for small animals. Two big animals, elephant and horse, and two small animals, butterfly and bird, were used. Before the beginning of the task, we ensure that children knew the four animals and were able to say that the horse and the elephant are big animals whereas the butterfly and the bird are small animals. In the control phase, composed of twelve trials, all pictures were presented with the same medium size. Thus, no interference arose from the size at which the animals were depicted in the picture. Before the training phase, children were informed that in the next phase, the size of the image would change but no matter the size of the image, they will have to say if it is a big animal or a small animal "in real life". Children had an illimited time to respond. Feedbacks were provided after every trial. The goal of this phase was to ensure that children managed to correctly sort the animals in this phase, as the size congruency manipulation on the Animal Size Stroop task is dependent on animal size knowledge. In the training phase, two different sizes of pictures were used. Big and small animals could be displayed on the screen either with a big size, either with a small size. Thus, in the congruent trials, the size of an animal in the real world was congruent with its size on the picture whereas in the incongruent trials the size of the real animal was not congruent with the size of the picture. Thus, these incongruent trials elicited interference related to the picture size since participants were compelled to inhibit a response to the pictorial size and to give a response related to the real animal's size. All the animals were presented twice with each size of pictures for a total of sixteen trials. Finally, the practice phase was identical to the training phase except that thirty-two trials (four animals presented with the two sizes, four times each) were performed by the children, and feedbacks were no longer provided. We computed an interference score with the difference between the average RT for the congruent trials (*M* = 1365, *SD* = 365) and the average RT for the incongruent trials (*M* = 1348, *SD* = 324). Higher scores indicate better inhibition, whilst lower scores indicate poorer inhibition.

8.3.4.4. World knowledge

We tested children's world knowledge with a vocabulary test, the EVIP which is a French adaptation (Canadian norms) of the PPVT (Peabody Picture Vocabulary Test, Dunn & Dunn, 2007). Vocabulary tests such as the EVIP are considered to be a good proxy for world knowledge because selecting the correct answer depends on the knowledge of the stimuli. In this test, children had to select one out of four images associated with a noun given by the experimenter. Responses were recorded on a paper sheet and a standard score was computed according to the age.

8.4. Results

To test whether the relationship between food rejection and categorization performance is mediated by cognitive flexibility, we followed a four steps analysis strategy. First, we tested the prediction that food rejection was inversely related to categorization performance. Second, we tested the prediction that food rejection was inversely related to executive function, more particularly cognitive flexibility. Third, we assessed whether children's executive functions were predictive of their categorization performance when controlling for an individual's world knowledge and food naming. Finally, if food rejection is related to children's categorization performance and executive functions and that executive functions were predictive of categorization performance when controlling for other individual variables, we will examine the mediating effect of executive functions on the relationship between food rejection and categorization performance.

All analyses were performed in the R environment. For the first step, we performed individual regressions using the *lm* function from the *stats* package (R Core Team, 2019). For the second and third steps, we performed hierarchical regressions. Finally, the mediating effect of executive functions on the relationship between food categorization accuracy and food rejection dispositions was tested using general linear model mediation modeling. We used 5.000 bias-corrected (BC) bootstrap samples for the total, direct, and indirect effects (MacKinnon et al., 2004). The effects and path coefficients were expressed as standardized estimates.

Descriptive statistics for the children in this study can be seen in Table 6.

	Children (n = 122) Mean (*SD*)
Age (in months)	67.4 (4.05)
Global food rejection	31.4 (8.31)
Food neophobia	15.2 (4.89)
Food pickiness	16.2 (4.34)

Categorization accuracy	0.837 (0.115)
Food naming	0.590 (0.145)
World knowledge	117 (18.0)
Working memory	6.10 (2.18)
Inhibition	0.78 (221)
Cognitive flexibility	5.18 (1.11)

Table 6. Descriptive statistics for age, food rejection scores, food categorization accuracy and naming, and the cognitive assessment scores.

SD: standard deviation

Associations among children's food rejection scores, food categorization accuracy and naming, and the cognitive assessment scores can be seen in Table 7.

	Global food rejection	Food neophobia	Food pickiness	Categorization accuracy	Food naming	World knowledge	Working memory	Inhibition	Cognitive flexibility
Global food rejection		r = .898 p < .001	r = .867 p < .001	r = -.301 p < .001	r = -.035 p = .701	r = -.077 p = .400	r = -.128 p = .160	r = -.031 p = .733	r = -.310 p < .001
Food neophobia	r = .898 p < .001		r = .581 p < .001	r = -.288 p = .001	r = -.106 p = .246	r = -.154 p = .090	r = -.148 p = .105	r = -.118 p = .201	r = - .259 p = .004
Food pickiness	r = .867 p < .001	r = .581 p < .001		r = -.262 p = .004	r = .037 p = .690	r = .024 p = .796	r = -.090 p = .323	r = .016 p = .858	r = - .270 p = .003
Categorization accuracy	r = -.301 p < .001	r = -.288 p = .001	r = -.262 p = .004		r = .506 p < .001	r = .190 p = .036	r = .348 p < .001	r = .059 p = .521	r = .336 p < .001
Food naming	r = -.035 p = .701	r = -.106 p = .246	r = .037 p = .690	r = .506 p < .001		r = .285 p = .001	r = .320 p < .001	r = .081 p = .378	r = .261 p = .004
World knowledge	r = -.077 p = .400	r = -.154 p = .090	r = .024 p = .796	r = .190 p = .036	r = .285 p = .001		r = .432 p < .001	r = -.017 p = .853	r = .222 p = .014
Working memory	r = -.128 p = .160	r = -.148 p = .105	r = -.090 p = .323	r = .348 p < .001	r = .320 p < .001	r = .432 p < .001		r = .045 p = .629	r = .339 p < .001
Inhibition	r = -.031 p = .733	r = -.118 p = .201	r = .016 p = .858	r = .059 p = .521	r = .081 p = .378	r = -.017 p = .853	r = .045 p = .629		r = -.112 p = .223
Cognitive flexibility	r = -.310 p < .001	r = - .259 p = .004	r = - .270 p = .003	r = .336 p < .001	r = .261 p = .004	r = .222 p = .014	r = .339 p < .001	r = -.112 p = .223	

Table 7. Spearman correlation coefficients among children's food rejection scores, food categorization accuracy and naming, and the cognitive assessment scores.

8.4.1. Food rejection and categorization

To test our hypothesis that food rejection negatively is associated with categorization performance, we first analyzed whether food rejection was a significant predictor of decreased categorization accuracy. Consistent with previous findings (e.g., Rioux et al., 2016), we found that children's mean categorization accuracy scores were negatively associated with food rejection ($\beta = -.317$, $t = -3.66$, $p < .001$).

8.4.2. Food rejection and other factors

To test our second hypothesis that food rejection is negatively related to cognitive flexibility, we analyzed whether food rejection was significantly associated with decreased cognitive flexibility whilst controlling for other individual variables. Table 8 shows the hierarchical regression analysis of the relations among children's executive functions scores (i.e., working memory, cognitive flexibility, and inhibition), knowledge scores (i.e., food naming and world knowledge), and food rejection scores. We found that children's food rejection scores were negatively associated with cognitive flexibility (β = -.314, t = -3.17, p = .002). No association was found for working memory, inhibition, food naming, and general world knowledge (p > .05).

	Food rejection		
	β	t	p
Food naming	.057	0.58	.561
World knowledge	.040	0.38	.703
Working memory	-.070	-0.66	.510
Cognitive flexibility	-.314	-3.17	.002
Inhibition	-.061	0.67	.505

Table 8. Relations among executive functions scores (i.e., working memory, cognitive flexibility, and inhibition), knowledge scores (i.e., food naming and world knowledge), and food rejection scores.

8.4.3. Other factors and categorization

The previous analyses established that food rejection was negatively associated with both food categorization performance and cognitive flexibility. Before testing our main hypothesis that cognitive flexibility mediates the relationship between food rejection and categorization performance, we need to assess whether cognitive flexibility is predictive of categorization accuracy. Table 9 shows the hierarchical regression analysis of the relations among children's executive functions scores (i.e., working memory, cognitive flexibility, and inhibition), knowledge scores (i.e., food naming and world knowledge), and categorization accuracy. We found that children's mean categorization accuracy scores were positively associated with food naming, working memory, and cognitive flexibility (p < .05). No association was found for inhibition and general world knowledge (p > .05).

	Categorization accuracy		
	β	t	p
Food naming	.447	5.66	<.001
World knowledge	-.101	-1.19	.237
Working memory	.210	2.44	.016
Cognitive flexibility	.252	3.12	.002
Inhibition	.047	0.63	.530

Table 9. Relations among executive functions scores (i.e., working memory, cognitive flexibility, and inhibition), knowledge scores (i.e., food naming and world knowledge), and categorization accuracy.

8.4.4. Do increased food rejection leads to decreased categorization accuracy through a mediating effect of decreased cognitive flexibility?

The main purpose of this experiment was to test the mediating effect of cognitive flexibility on the relationship between food rejection and categorization accuracy. Results of the regression analyses showed that food rejection was negatively associated with categorization accuracy and cognitive flexibility. We thus conducted a mediation analysis to investigate how cognitive flexibility mediated the effect of food rejection on categorization accuracy. We tested the significance of the indirect effect using bootstrapping procedures (i.e., the effect of food rejection on categorization is mediated by cognitive flexibility). Standardized indirect effects were computed for each of 5,000 BC bootstrap samples (MacKinnon et al., 2004). The mediation analysis (Figure 11) met the four conditions enunciated by Baron and Kenny (1986), namely significant relations between food rejection and cognitive flexibility (β = -.315, p < .001), between cognitive flexibility and categorization accuracy (β = .351, p < .001), and between food rejection and categorization accuracy (β = -.317, p < .001), as well as a reduced impact of food rejection on categorization accuracy (β = -.207, p = .009). The analysis revealed that the indirect effect of food rejection on categorization via the mediation cognitive flexibility was significantly different from zero (β =-.111, z = -2.81, p = .005). However, as shown by the Sobel test (Sobel, 1982) the standardized direct effect (i.e., the remaining effect of food rejection on categorization whilst considering the influence of cognitive flexibility) remained significant after the inclusion of cognitive flexibility (z = -2.61, p = .009).

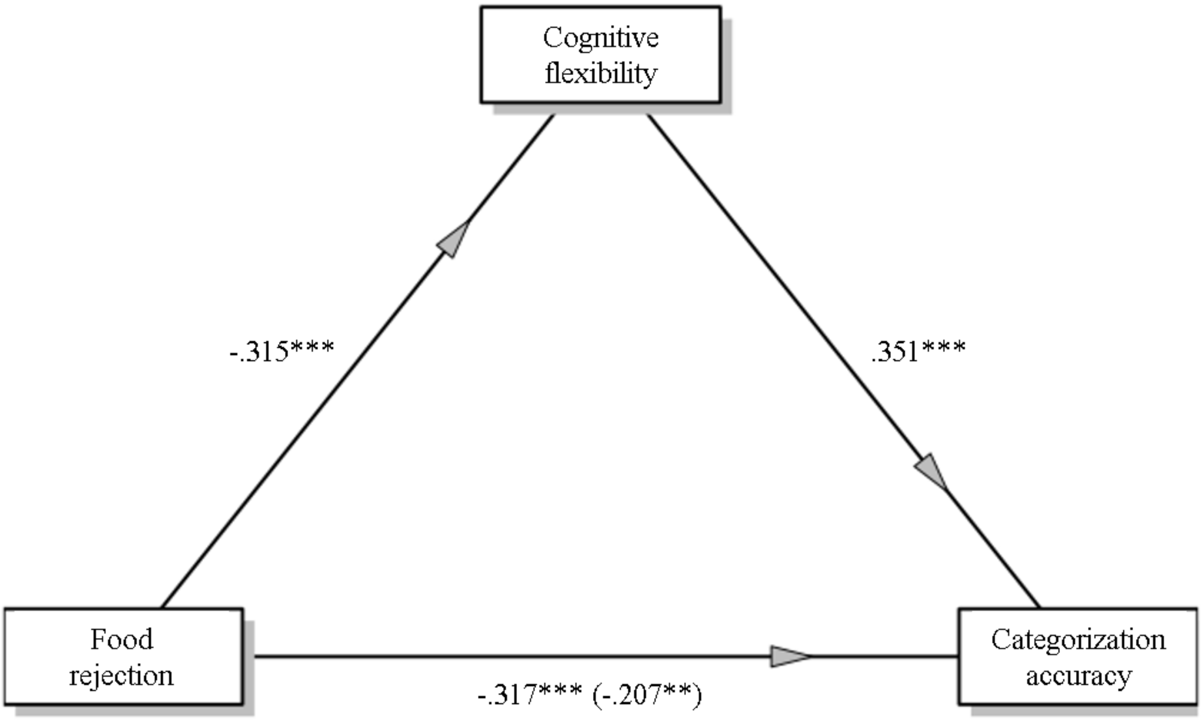

Figure 11. Mediation model diagram.

Note. *** $p < .001$, ** $p < .01$, * $p < .05$

8.5. Discussion Experiment 1

This experiment is the first, to the best of our knowledge, focusing on the combined influence of children's cognitive mechanisms (i.e., executive functions) and food rejection dispositions (i.e., food neophobia and pickiness) on their categorization performance. The results provided evidence in favor of our three hypotheses. The most important result was that they provide the first evidence that children's cognitive flexibility mediates the relationship between food rejection and categorization abilities. Second, children's levels of food rejection also negatively predicted their performance on the cognitive flexibility task (i.e., more neophobic meant less flexible). Third, children's levels of food rejection negatively predicted their categorization performance, with more neophobic and picky children performing more poorly in the categorization task than their more neophilic and less picky counterparts, which is consistent with former findings on the negative relationship between categorization abilities and food rejection (Foinant et al., 2021a; Pickard et al., 2021b; Rioux et al., 2016).

Our study goes beyond such previous studies with the addition of the cognitive component to the picture, showing that neophobic and picky children's categorization limitations may, in fact, reflect their inability to flexibly apply their conceptual knowledge. This result is important since it is the first one contributing to ground the relationship between food rejection and categorization abilities in central monitoring processes.

8.6. Experiment 2: Flexible categorization task

The first experiment tested the hypothesis that the effects of food rejection on categorization abilities could be attributed to decreased knowledge but also to lower levels of cognitive flexibility. We also found a mediating effect of cognitive flexibility. The second experiment pushed this logic a step further and tested children's *categorical flexibility* and its relations with the cognitive and knowledge factors we considered in Experiment 1. We used a double categorization task that explicitly asked children to flexibly categorize foods (Blaye & Jacques, 2009). It tested whether children would be able to select a second food to associate with a target food after the selection of a first food. The first food choice was a taxonomic choice and the second food choice was a thematic choice whereas the third was an unrelated choice. The purpose was to test whether neophobic and picky children would have difficulties selecting a second food choice that would differ from the first food choice. We hypothesized that since the double selections required categorical flexibility, we should find a fully mediating effect of cognitive flexibility on the relationship between food rejection and categorization performance.

8.6.1. Participants

Participants were 100 children (55 girls and 45 boys; age range = 37.20 to 75.20 months; mean age = 61.10; *SD* = 9.29). Informed consent was obtained from their school and their parents. The procedure was in accordance with the Declaration of Helsinki and followed institutional ethics board guidelines for research on humans. None of these children participated in Experiment 1.

8.6.2. Materials – categorization task

As in the previous study, the caregivers filled out the CFRS (food neophobia scores, *M* = 15.1, *SD* = 5.64; food pickiness scores, *M* = 16.4, *SD* = 4.71; and global food rejection scores, *M* = 31.5, *SD* = 9.53).

We constructed 11 stimuli made of 4 color photographs of real food. Each stimulus was presented on an A4 sheet displayed horizontally with the target (e.g., a lemon) at the top and centered, and three tests (three foods) on the same line below the target (see Figure 12). Among these three tests, one was a superordinate taxonomic choice (e.g., another fruit, a pear), another was a thematic option (e.g., codfish), and the remaining one was an unrelated food (e.g., a natural-flavored yogurt). The spatial location (left, middle, or right) of the three types of tests (taxonomic, thematic, or unrelated) was counterbalanced. Two additional nonfood stimuli were used in demonstration trials.

Figure 12. Example of a stimulus. The target corresponds to the lemon, the taxonomic choice to the pear, the thematic choice to the cod, and the unrelated choice to the natural-flavored yogurt.

Three independent groups of 20 adults participated in rating tasks to ensure that each item in the three types of test items belonged to the test type it was hypothesized to belong to, that is either taxonomically related or thematically related or unrelated. We also tested whether the three tests were perceptually dissimilar to the target. Each group was shown 16 stimuli in the same format as in the actual task (a target and three potential tests) in a counterbalanced order. The first group was asked to rate on a 7-point Likert-like scale to what extent each test belonged to the same taxonomic category as the target. The second group was asked to rate on a 7-point Likert-like scale to what extent each test was frequently associated in the same context with the target (i.e., whether the target and the test often appear *together* in the same context). The third group rated perceptual similarity between each test and the target on a 7-point Likert-like scale (see Appendix 6, for the details of the ratings). Descriptive statistics can be found seen in Table 10. We only kept stimuli with ratings significantly lower than 4 for perceptual similarity. For taxonomic ratings, we kept stimuli with taxonomic ratings significantly lower than 4 for each non-taxonomic choice and a taxonomic rating significantly higher than 4 for the taxonomic choice. For thematic ratings, we kept stimuli with thematic ratings significantly lower than 4 for each non-thematic choice and thematic ratings significantly higher than 4 for the thematic choice (see Appendix 6 for the rating and *t*-tests).

	The three types of tests		
Ratings	Taxonomic	Thematic	Unrelated
Perceptual	2.13 (0.60)	2.11 (0.82)	1.81 (0.47)
Taxonomic	5.58 (0.91)	2.81 (1.46)	1.60 (0.55)
Thematic	3.32 (1.10)	5.96 (0.97)	1.59 (0.57)

Table 10. Mean perceptual, taxonomic, and thematic ratings for the three types of tests of 16 stimuli.

Standard deviation in brackets.

8.6.3. Procedure – categorization task

Children were tested individually in their school. The task began with two nonfood training trials. In each trial, children were asked to select two tests for each target. For their First Selection, children were told (in French), "Look at this (the experimenter pointing to the target). Can you show me, among these three (the experimenter designing the potential tests), the one that goes best with this one (pointing again to the target)? To show me, place this coin on top of the one you chose." For their Second Selection, they were told, "Now there are only two left. Can you show me out of these two (designing the choices without coin), which goes better with this one (pointing to the target)? Here is another coin to indicate your choice". If children selected the unrelated test for either selection in the demonstration trials, they received corrective feedback in that the coin was moved to the correct associate. The order of the two demonstration trials was counterbalanced across participants. After the two demonstration trials, 11 test trials were presented with no corrective feedback. For the First Selection, a score of 1 was given when participants successfully selected one of the two correct tests (i.e., taxonomic or thematic), and a score of 0 was given when they selected the unrelated food. We then assigned each participant a mean First Selection accuracy score and a mean Second Selection accuracy score that was dependent on performance on the First Selection (i.e., trials where children selected the unrelated food on their First Selection were not taken into account for the computation of the Second Selection accuracy). Based on their First Selection and Second Selection accuracy scores, children were assigned a Double Selections accuracy score (i.e., the proportion of trials for which participants made two correct selections).

8.6.4. Procedure – Cognitive assessment tasks

The procedure for the cognitive assessment task was the same as in the first experiment. We collected children's cognitive flexibility, working memory, inhibition, and world knowledge. We respectively used the DCCS (Zelazo et al., 2013), the List Sorting (Tulsky et al., 2014), the RAST (Catale & Meulemans, 2009), and the EVIP (Dunn & Dunn, 2007).

8.7. Results

A control group of adults (n = 40) also performed the categorization task to ensure that our taxonomic and thematic tests would indeed be selected appropriately. These participants were university students from a French University. Adults' performance on the Double Selections was significantly above 0.33 (Double Selections scores are dependent of First Selection performance; p = 0.67 for First Selection and p = 0.50 for Second Selection, thus, p = 0.33 for both; M = 0.941, SD = 0.073; t = 53.0, p < .001, d = 8.38).

For children's data, we followed the same statistical analyses strategy as in the first experiment. We ran regression analyses to test the predictions that food rejection was inversely related to Double Selections accuracy, and cognitive flexibility. We tested whether cognitive flexibility was predictive of Double Selections accuracy when controlling for an individual's other executive functions and world knowledge. Finally, if food rejection was predictive of children's Double Selections accuracy and cognitive flexibility, and that cognitive flexibility was predictive of Double Selections performance when controlling for other individual variables, we would examine the mediating effect of cognitive flexibility on the relationship between food rejection and Double Selections performance.

Descriptive statistics for the children in this study can be seen in Table 11.

	Children (*n* = 100) Mean (*SD*)
Age (in months)	61.1 (9.39)
Global food rejection	31.5 (9.53)
Food neophobia	15.1 (5.67)
Food pickiness	16.4 (4.71)
Double Selections	0.640 (0.175)
World knowledge	120 (16.6)
Working memory	5.89 (2.04)
Inhibition	-5.37 (228)
Cognitive flexibility	4.89 (1.23)

Table 11. Descriptive statistics for age, food rejection scores, Double Selections accuracy, and the cognitive assessment scores.

SD: standard deviation

Associations among children's food rejection scores, food categorization accuracy, and the cognitive assessment scores can be seen in Table 12.

	Global food rejection	Food neophobia	Food pickiness	Double Selections	World knowledge	Working memory	Inhibition	Cognitive flexibility
Global food rejection		r = .940 p < .001	r = .880 p < .001	r = -.275 p = .006	r = -.153 p = .127	r = -.080 p = .430	r = -.018 p = .860	r = -.392 p < .001
Food neophobia	r = .940 p < .001		r = .685 p < .001	r = -.333 p < .001	r = -.198 p = .049	r = -.044 p = .661	r = -.017 p = .868	r = -.346 p < .001
Food pickiness	r = .880 p < .001	r = .685 p < .001		r = -.156 p = .122	r = -.049 p = .627	r = -.132 p = .189	r = -.046 p = .649	r = -.352 p < .001
Double Selections	r = -.275 p = .006	r = -.333 p < .001	r = -.156 p = .122		r = .366 p < .001	r = .188 p = .061	r = -.172 p = .087	r = .410 p < .001
World knowledge	r = -.153 p = .127	r = -.198 p = .049	r = -.049 p = .627	r = .366 p < .001		r = .257 p = .010	r = -.147 p = .144	r = .358 p < .001
Working memory	r = -.080 p = .430	r = -.044 p = .661	r = -.132 p = .189	r = .188 p = .061	r = .257 p = .010		r = -.059 p = .557	r = .272 p = .006
Inhibition	r = -.018 p = .860	r = -.017 p = .868	r = -.046 p = .649	r = -.172 p = .087	r = -.147 p = .144	r = -.059 p = .557		r = -.097 p = .338
Cognitive flexibility	r = -.392 p < .001	r = -.346 p < .001	r = -.352 p < .001	r = .410 p < .001	r = .358 p < .001	r = .272 p = .006	r = -.097 p = .338	

Table 12. Spearman correlation coefficients among children's food rejection scores, Double Selections accuracy, and the cognitive assessment scores.

8.7.1. Food rejection and categorization

Children exhibited categorical flexibility if they selected alternatively the two correct choices per series. Considering that in Experiment 1, neophobic and picky children were found to have poorer categorization and cognitive flexibility than the neophilic and less picky children, we hypothesized that they would exhibit poorer categorical flexibility. We found that children's mean Double Selections accuracy scores were negatively associated with food rejection (β = -.263, t = -2.70, p = .008).

8.7.2. Food rejection and other factors

To confirm that food rejection is negatively related to cognitive flexibility, we analyzed whether food rejection was significantly associated with decreased cognitive flexibility among other executive functions (i.e., working memory and inhibition) and world knowledge (Table 13). We found that children's food rejection scores were negatively associated with cognitive flexibility (β = -.398, t = -3.64, p < .001). No association was found for working memory, inhibition, and general world knowledge (p > .05).

	Food rejection		
	β	t	p
World knowledge	.004	0.03	.974
Working memory	.036	0.350	.727
Cognitive flexibility	-.398	-3.64	<.001
Inhibition	-.079	-0.79	.434

Table 13. Relations among executive functions scores (i.e., working memory, cognitive flexibility, and inhibition), world knowledge, and food rejection scores.

8.7.3. Other factors and categorization

The previous analyses established that food rejection was negatively associated with both food categorization performance and cognitive flexibility. Before testing our hypothesis that cognitive flexibility mediates the relationship between food rejection and categorization performance, we need to assess whether cognitive flexibility is predictive of Double Selections accuracy. Table 14 shows the hierarchical regression analysis of the relations among children's cognitive, and knowledge, scores, and Double Selections accuracy. We found that children's mean Double Selections accuracy scores were positively associated with world knowledge and cognitive flexibility ($p < .05$). No relationships were found for inhibition and working memory ($p > .05$).

	Double Selections accuracy		
	β	*t*	*p*
World knowledge	.215	2.04	.041
Working memory	.013	0.13	.897
Cognitive flexibility	.305	2.93	.004
Inhibition	-.070	-0.73	.466

Table 14. Relations among the cognitive, and knowledge, scores, and categorization accuracy.

8.7.4. Do increased food rejection leads to decreased categorization accuracy through a mediating effect of decreased cognitive flexibility?

We aimed to test the mediating effect of cognitive flexibility on the relationship between food rejection and categorical flexibility. We conducted a mediation analysis to investigate how cognitive flexibility mediated the effect of food rejection on Double Selections accuracy. We tested the significance of the indirect effect using bootstrapping procedures (i.e., the effect of food rejection on categorization is mediated by cognitive flexibility). Standardized indirect effects were computed for each of 5,000 BC bootstrap samples (MacKinnon et al., 2004). The mediation analysis (Figure 13) met the four conditions enunciated by Baron and Kenny (1986), namely significant relations between food rejection and cognitive flexibility ($\beta = -.365$, $p < .001$), between cognitive flexibility and Double Selections accuracy ($\beta = .372$, $p < .001$), and between food rejection and Double Selections accuracy ($\beta = -.263$, $p < .007$), as well as a reduced impact of food rejection on Double Selections accuracy in the standardized direct effect which did not remain significant ($\beta = -.127$, $p = .183$).The Sobel test (Sobel, 1982), showed that, as predicted by our main hypothesis, the indirect effect of food rejection on Double

Selections via the mediation of cognitive flexibility was significantly different from zero (β =-.136, z = -2.86, p = .004).

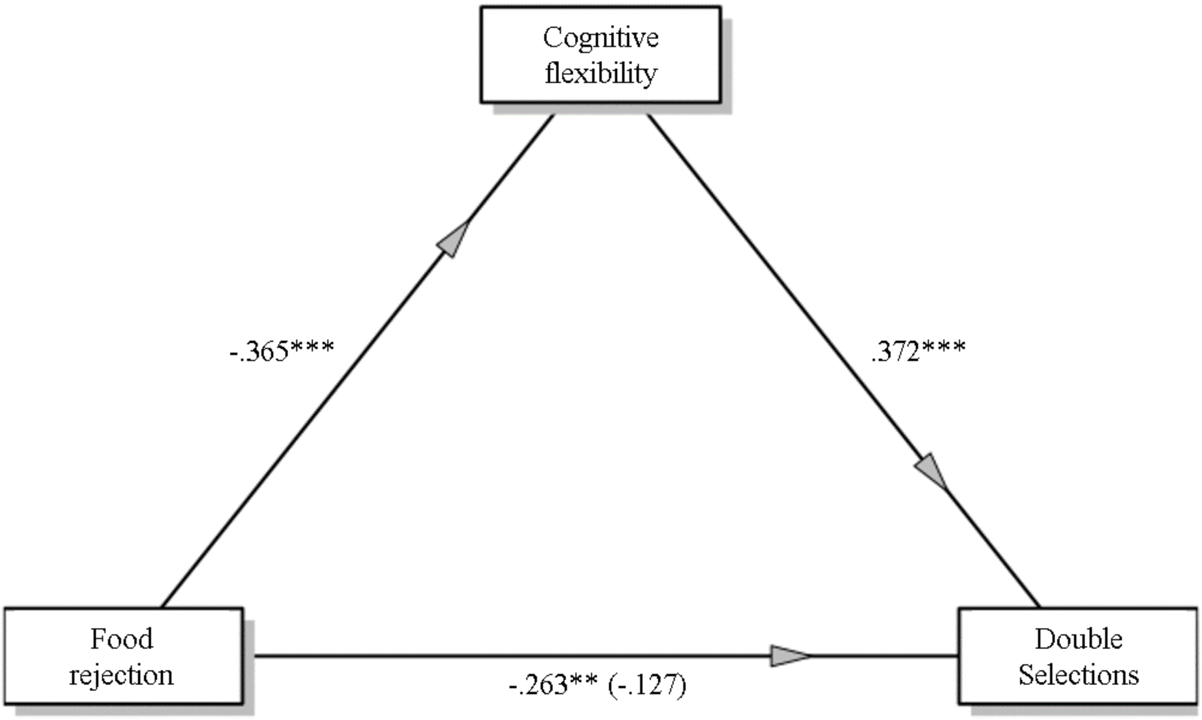

Figure 13. Mediation model diagram.
Note. *** p < .001, ** p < .01, * p < .05

8.8. Discussion Experiment 2

Experiment 2 aimed to extend the findings from Experiment 1 using a task testing categorical flexibility. The most important result was that we confirmed the role of cognitive flexibility as a mediator of the relationship between food rejection and categorization abilities. Results revealed that neophobic and picky children had more difficulties associating successively the same foods in two conflicting categories than their more neophilic and less picky counterparts. Furthermore, as in the first experiment, food rejection was negatively related to cognitive flexibility.

8.9. General discussion

Two experiments investigated the role of executive functions in the relationship between food rejection and categorization. To the best of our knowledge, these experiments are the first to examine the multiple relationships between food rejection, executive functions, world knowledge, and children’s difficulties in food categorization tasks, highlighting the mediating role of cognitive flexibility.

In both experiments, we found that food rejection scores predicted poorer categorization performance. This pattern supports our prediction and is consistent with previous findings showing that neophobic and picky children have poor categorization abilities, in both taxonomic categorization tasks (Foinant et al., 2021a; Rioux et al., 2016; 2017b) and thematic categorization tasks (Pickard et al., 2021a). Beyond these results, our two experiments demonstrated the implication of cognitive flexibility as a mediating factor in categorization tasks, and the association between food rejection and executive functions, in a taxonomic categorization task (Experiment 1) and in a categorization requiring a shift from taxonomic to thematic categorization and vice versa (Experiment 2). In this second experiment, levels of food rejection predicted poorer ability to select an alternative form of categorization after having selected a first conflicting form of categorization. Thus, food rejection is related to decreased taxonomic and thematic conceptual knowledge but also to lower performance when one has to switch between conceptually relevant relations.

Our general hypothesis was that categorization is related to the development of executive functions, in particular cognitive flexibility (Blaye & Jacques, 2009; Lagarrigue & Thibaut, 2020). In our data, cognitive flexibility was consistently found to be predictive of children’s categorization performance, whereas the evidence was mixed for other executive functions and world knowledge. We found positive influences of working memory in the first experiment, and of general world knowledge in the second. The effect of working memory on a task pitting two closely related superordinate categories (i.e., vegetables and fruits) is in line with Halford et al.'s proposal (1998). Accordingly, children’s ability to process multiple dimensions in parallel depends on the sophistication of working memory. Particularly, that young children would struggle with abstract dimensions such as category membership due to increased pressure on working memory. The effect of world knowledge on children’s categorical flexibility suggests that children with richer world databases also know more associations between objects, in our case foods. Of note, we did not find an effect of inhibition which has been uncovered in other studies (Rabi & Minda, 2014; Snape & Krott, 2018). However, in comparison, none of our tasks involved interferences, which may explain this absence of effects.

In conclusion, our experiments are the first to provide evidence for the key role of cognitive flexibility in the relation between food rejection and categorization. The results allow to precise the interpretation of the relation between food rejection and categorization abilities. For some researchers, due to reduced interaction with different food categories, neophobic and picky children end up lacking the conceptual knowledge related to these categories (Harris, 2018; Rioux et al., 2016). In light of our findings, those children may, instead, lack the cognitive flexibility needed to understand and identify the relevant conceptual relations in a given context (e.g., taxonomic, thematic, health, etc.). If rather than impoverished concepts of food, the difficulties of neophobic and picky children for interacting with their food environment lies with the development of more general cognitive abilities, we could expect similar difficulties in categorization tasks that do not involve solely food stimuli or situations.

This more general perspective also opens up promising practical perspectives. According to our findings, the children who have more difficulties switching from one conceptual representation to another (e.g., from taxonomic to thematic) are more likely to be neophobic and picky. Therefore, it could be beneficial to teach children about the different categories of food, and not solely that there are healthy and unhealthy foods. It might be more effective to improve children's knowledge about the healthiness of food, but also what the food is, in which context it is eaten, with what, etc.

PART D. GENERAL DISCUSSION

The literature on children's food conceptual knowledge demonstrated a clear developmental progression between 2-to-7-years of age (e.g., Nguyen & Murphy, 2003; Rioux et al., 2016; Thibaut et al., 2016). This age range has been identified as the sensitive period for food neophobia and pickiness, the two main kinds of food rejection (Dovey et al., 2008; Lafraire et al., 2016b). Recent studies have investigated the relations between preschool-aged children's food rejection and their categorization abilities (e.g., Pickard et al., 2021a; Rioux et al., 2016).

The findings from those studies suggest that we could be facing a vicious circle. Food rejection was found inversely related to knowledge about the food domain. Impoverished knowledge increases children's uncertainty about foods and eating situations. This uncertainty can lead children to further reject novel and familiar foods or eating situations. Withdrawn from learning opportunities, neophobic and picky children's food knowledge remains underdeveloped, thus perpetuating the vicious circle.

The present thesis investigated whether i) it was possible to break the vicious circle using visual signs such as cues of food processing to reduce children's uncertainty about the edibility of substances, and ii) this circle was only related to the amount of knowledge or that children's developing executive functions were also at play, mediating the use of their conceptual knowledge about foods.

9.1. Food neophobia and the role of food processing to reduce perceived uncertainty and risk

In the food domain, one mistake can be fatal. Nevertheless, for physical and cognitive health a dietary variety is needed (Evans et al., 2018). Therefore, there is a balance between benefits (a more diverse diet) and risks (eating something inedible or toxic) when deciding to include novel foods in one's diet (Crane et al., 2020). Neophobic individuals may err on the side of caution rejecting novel foods, even though it means being limited to a small sample of familiar foods. For neophobic children, simply repeated exposures to the novel foods may not be enough to promote acceptance (e.g., Rioux et al., 2018a). Thus, it is important to understand how we could reduce their uncertainty to allow them more experiences with novel foods. The present thesis investigated whether a stimulus displaying cues of food processing would be perceived as safer and accepted more easily as a potential food source than unprocessed stimuli.

According to this proposition, the first twofold objective of the present thesis was:

1) To investigate children's reasoning about the health consequences of food consumption as a function of their neophobia and the state of processing of the stimuli.

2) To test the double influence of children's food neophobia on their categorization performance and strategy as a function of the processing state of the stimuli.

9.1.1. Children' s reasoning about the health consequences of food consumption

From 3 years of age, children understand that foods and food properties can be sorted as positive or negative (Nguyen and Murphy, 2003; Nguyen, 2007). Further, they can productively use the distinction between positive and negative foods to make inferences about health (Nguyen, 2008).

To test for the influence of food neophobia and food processing on children's response strategies in situations of increased food risk, an induction task has been proposed to 126 children, aged 3-6 years. Children were required to generalize positive (e.g., "gives Feppy strength") or negative health-related properties (e.g., "makes Feppy throw up") for familiar and unfamiliar foods, whole or sliced. We contrasted these four categories of foods to test for the influence of the food processing variable to cue edibility (Coricelli et al., 2019; Rioux & Wertz, 2021). We hypothesized that cues of food processing should reduce children's uncertainty regarding the edibility of a food, at least for unfamiliar foods that they had no prior knowledge about (Chapter 5).

The results suggest that the familiar fruits and vegetables were perceived as safe. Indeed, whereas children generalized to these familiar foods the positive properties (i.e., above chance), they did not generalize the negative properties (i.e., below chance). For the unfamiliar fruits and vegetables, we observed a reverse pattern. Children generalized the positive properties to the unfamiliar foods below chance and the negative properties above chance. In sum, children were more cautious in the case of unfamiliar foods. However, children were less cautious regarding the sliced unfamiliar foods. For the unfamiliar fruits and vegetables exhibiting cues of food processing, children generalized more positive and less negative properties to these foods than they did to the whole unfamiliar tests. Therefore, when children cannot rely on prior knowledge, food processing may serve as visual cues to alleviate their fear about the edibility of a food.

The results of this experiment confirm former findings showing that children productively use their prior knowledge about food, in the case of familiar foods, when reasoning on the consequences of consumption (e.g., Nguyen, 2008; Thibaut et al., 2020). However, the experiment also showed in the absence of prior knowledge, children were sensitive to other conceptual cues related to edibility such as food processing. Whereas the influence of food processing had been demonstrated with adults (e.g., Coricelli et al., 2019) and, very recently, infants (Rioux & Wertz, 2021), our experiment (Foinant et al., 2021) is the first contribution with preschool-aged children. Taken together, all these contributions establish a remarkable continuity across ages.

Finally, we also found that children with high levels of food neophobia extended more negative properties to all foods regardless of their familiarity and their degree of processing (i.e., raw or processed). Importantly, this suggests that food neophobia is related to the notion of perceived risk (Crane et al., 2020), as only the negative properties were influenced by this disposition. Furthermore, contrary to our expectations food neophobia did not only target unfamiliar foods. It appears that neophobic children would over-execute caution in situations of risk, being willing to consider as potentially dangerous familiar and processed foods. This over caution witnessed is in line with Rioux and Wertz's (2021) findings who found that the more neophobic children were also the infants who were the less willing to approach sliced foods a year before.

To summarize, our results suggest that children can use cues of food processing when deciding that a substance is safe in situations of uncertainty (i.e., with unfamiliar foods). On the other hand, neophobic children disregarded these cues, generalizing more negative properties than their more neophilic counterparts to the four categories of food we created, including processed foods.

9.1.2. Influence of children’ s food neophobia on categorization performance and strategy

Our previous experiment on reasoning about the health consequences of food consumption highlighted that neophobic children would adopt cautious response strategies in a situation involving food risks. They would overreact and ignore safety cues such as food processing. However, the paradigm we used was not grounded in the assumption that there were no correct or incorrect responses. It investigated children’s patterns of induction, which did not allow the investigation of an important aspect of neophobia covered in this thesis: the poorer categorization performance of neophobic children as compared to their neophilic counterparts.

To measure simultaneously children’s categorization performance and decision strategy we used the theoretical framework of Crane and colleagues (2020) based on the SDT. The SDT provides a framework for how individuals adapt their strategies as a function of their ability to recognize potentially dangerous stimuli.

To study the categorization performance and decision strategy of children with food neophobia using the SDT, we designed two edibility categorization tasks because such tasks are characterized by asymmetrical costs that might reveal children's response strategies when confronted with risk in the food domain. Indeed, in this task mistaking a non-edible item for an edible one is not equivalent to mistaking an edible item for a non-edible one, the first mistake might lead to intoxication or death whereas the second one prevents getting some nutrients. We tested young children's abilities to discriminate fruits and vegetables from nonfoods matched on color and shape (e.g., a red tomato and a red Christmas ball). Experiment 1 was a forced-choice task in which 120 children between 4 and 6 years had to discriminate between foods and similar-looking nonfoods. Experiment 2 included processed foods and nonfoods to test the influence of different levels of perceived uncertainty on 137 children's categorization (Chapter 6).

The results from this first experiment showed that not only children's food neophobia negatively predicts discrimination accuracy for foods and nonfoods, but also their decision strategies. Neophobic children were found to favor increases of misses to avoid mistaking nonfoods for foods. In the next experiment, we investigated whether cues of food processing would increase children' strategy to categorize the stimuli as food, such that children should respond more that sliced stimuli are food than whole stimuli. Indeed, according to the existing findings, slicing reduces children's uncertainty with respect to stimulus edibility (e.g., Chapter 5). Therefore, we hypothesized that children would adopt a more liberal strategy for sliced stimuli than for whole stimuli, in particular the more neophilic children.

We, indeed, found that neophobic children adopted a more cautious decision strategy than more neophilic children and thus for both whole and sliced stimuli. On the other hand, neophilic children adopted a more liberal bias for sliced stimuli. They were more willing to accept sliced items as food, even nonfood items, thus committing hazardous categorization errors.

In line with our predictions, forced-choice tasks pitting a safer response (i.e., it is inedible) and a riskier response (i.e., it is edible) in an uncertain environment (i.e., nonfoods matching foods on color and shape) witnessed an association between children's food neophobia and their strategy of response. The more neophobic children made more "it is inedible" mistakes than their more neophilic counterparts. In the SDT framework, neophobic children favored misses over false alarms (Crane et al., 2020), thus being more cautious than other children. This result extends our findings in Chapter 5, showing that that food neophobia was related to the tendency to over execute caution.

We also found that food neophobia interacted with the stimuli's processing states to predict children's categorization strategy (Figure 9). In line with our expectations, whereas the more neophobic children did not adopt different strategies of responses for whole and sliced stimuli, the more neophilic children displayed a more liberal strategy for sliced stimuli than for whole stimuli. This result suggests that neophilic children are more sensitive to food processing as a safety cue, which can reduce perceived uncertainty as regard to stimulus edibility, than neophobic children.

This result may appear counterintuitive because highly neophobic children require more guarantees that food is safe than more neophilic children, and food processing has been found to cue safety. However, for neophobic children slicing may have been a degree of food processing too subtle. Indeed, if, in general, food neophobia decreases with social facilitation (for a review see DeJesus et al., 2018), children with high levels of food neophobia need greater amounts of social information (e.g., more social looking time with adults; Rioux & Wertz, 2021) to accept novel foods, than their more neophilic counterparts. Thus, whereas for neophilic children slicing was enough to reduce their uncertainty, for neophobic children higher degrees of food processing might be necessary. Future research could also explore the effect of stressing the intention of the chef who prepares food, or why preparing food is an important process. Indeed recent studies revealed that children who took part in culinary activities showed increases in their food acceptance (Allirot et al., 2016; Chu et al., 2014; DeJesus et al., 2019). By exposing children to food transformation processes of a raw product by interaction with a chef or parents, children's food risk perception may decrease which could lead to increased acceptance of the given food.

9.2. Executive functions, food rejection, and categorization abilities

It is assumed that food rejection is driven by fear of what is novel or different (Pliner & Hobden, 1992). Accordingly, the Knowledge Gaps Hypothesis proposes that more things appear novel or different for children with high food rejection due to their lack of knowledge about foods (Lafraire et al., 2016a; Rioux et al., 2016; 2017a). The present thesis tested the hypothesis that food rejection results from difficulties to adapt oneself to changes in the food environment and thus to use appropriately their previous knowledge. The executive functions that develop concurrently with food rejection (i.e., working memory, inhibition, and cognitive flexibility) are important to enable efficient understanding of conceptual relations (e.g., Lagarrigue & Thibaut, 2020). We hypothesized that part of the lower categorization performance witnessed in children with high levels of food rejection may be due to their undeveloped executive functions.

According to this proposition, the second twofold objective of the present thesis was:

1) To investigate the relationships between food rejection and executive functions in young children.

2) To disentangle the specific influences that children's food rejection and executive functions have on their categorization abilities.

9.2.1. Relationships between food rejection and executive functions in young children

Children with high food rejection display rigidity toward food-related situations (Harris, 2018), disregard novel foods (Dovey et al., 2008), and reject previously accepted foods because of small changes (Carruth et al., 1998). These behaviors were hypothesized to be a sign of a lack of cognitive monitoring necessary to manage their reactions or the strength of those reactions. This led us to test whether executive functions were related to food rejections and to their categorization performance.

We also assessed the influence of world knowledge. It has been argued that world knowledge is a key factor for conceptual abstraction and understanding in the sense that the more children know about the world, the more likely they will discover conceptually relevant dimensions (Gentner & Hoyos, 2017). Indeed, available evidence already suggested that food rejection is negatively related to children's knowledge of food, but also potentially to their general knowledge of the world (Rioux et al., 2018). Furthermore, knowledge learning has been found to be influenced by executive functions, with, for example, more flexible children being able to learn and use novel words more efficiently than more rigid children (Lagarrigue & Thibaut, 2020), which is consistent with what we observed in our categorization tasks (i.e., categorization performance of children with high food rejection was partly explained by cognitive rigidity, see Section 9.2.2. below).

The experiment (chapter 7), conducted with 240 children between 3 and 6 years, provides the first empirical evidence of associations among children's food rejection (as assessed by the CFRS), executive functions (i.e., working memory, inhibition, and cognitive flexibility), and world knowledge (as assessed by the EVIP). Another key result is that food neophobia and pickiness may not be associated with the same cognitive deficits or difficulties.

We, indeed, found that cognitive flexibility was negatively associated with both kinds of food rejection. However, further analysis revealed that food neophobia was a stronger predictor of children's cognitive flexibility than pickiness. Nonetheless, picky children were not only less flexible, but there were also found to lack inhibition, but to have greater world knowledge, as compared to less picky children (Table 5).

These findings are the first showing that food rejection dispositions are associated with underdeveloped executive functions. In the food domain, they contribute to extending previous work suggesting that cognitive flexibility is the most important executive function involved in well-studied food health-related issues such as obesity (Cserjési et al., 2007; Verdejo-Garcia et al., 2010) and anorexia nervosa (for a review see Roberts et al., 2007). For instance, at least two studies with children suggest that when measuring both cognitive flexibility and inhibition, obesity is more specifically associated with cognitive flexibility (Delgado-Rico et al., 2012; Verdejo-García et al., 2010). A similar conclusion can be drawn for anorexia nervosa patients. Stedal et al. (2012) showed that at 9 years of age, children with anorexia nervosa do not have specific difficulties on executive functions tasks, except for cognitive flexibility.

As for the difference witnessed between the predictive power of food neophobia over pickiness to explain children's cognitive flexibility, referring to evidence showing that food neophobia can be a stronger predictor than pickiness for conceptual understanding is enlightening (e.g., Pickard et al., 2021b; Rioux et al., 2018a). Neophobic children were found to have more difficulties than picky children in identifying the conceptual relation central to a task a hand or to generalize the properties of a food to other foods. Such difficulties may be related to underdeveloped cognitive flexibility which is central for efficient selections of correct conceptual relations (Lagarrigue & Thibaut, 2020; Simms et al., 2018), as well as to be able to generalize this behavior to new stimuli (Kharitonova et al., 2009). Therefore, food neophobia may be more strongly related to cognitive flexibility, which would in turn explains the more robust links found between food neophobia, rather than pickiness, and conceptual understanding.

Nevertheless, food pickiness was also found to be negatively associated with inhibition. Picky eaters are children who only eat a narrow repertoire of preferred foods, categorically refusing to retry a food previously disliked (Dovey et al., 2008; Taylor et al., 2015). Inhibition, the function of which is to allow control over impulsive responses (e.g., not sampling the familiar but disliked food) in order to adopt goal-oriented behaviors (e.g., sampling the food), has been found to be negatively correlated with children willingness to eat a disliked food (Rigal et al., 2016). Therefore, the negative association between inhibition and food pickiness is not surprising.

Picky children lack both inhibitory and flexibility skills. They might be unable to inhibit a previous negative hedonic experience (which makes much less sense for neophobic children who do not taste novel foods) which might also be due to an inability to flexibly redescribe novel foods or previous negative experience, which is the defining feature of cognitive flexibility. This general ambivalent attitude might explain the unexpected positive association between food pickiness and general world knowledge. To be picky, it is important to encode them very distinctively so that, later, children recognize them. Interestingly, these subtle judgments would be impossible with a looser encoding. This is compatible with the observation that picky eaters refuse foods that depart only slightly from the usual, prototypical, appearance of an accepted food.

Developing models of cognitive processing may be important for understanding why some young children are particularly neophobic and/or picky. As shown in our experiment, cognitive factors may allow a finer distinction between food neophobia and pickiness, which may be crucial to developing more specific and thus efficient interventions. Given that childhood food neophobia and pickiness have been linked to later health-related problems (Nicklaus et al., 2005) and that children's executive functions have been shown to be relatively stable (Miyake & Friedman, 2012), identifying associations between food rejection and executive functions at an early age could potentially be useful for clinicians and healthcare professionals working with children with feeding problems and with those who have or are at risk of disordered eating.

9.2.2. Food rejection and categorization: the mediating role of cognitive flexibility

Ultimately, we were aiming to find evidence of relations between food rejection and executive functions because we made the hypothesis that neophobic and picky children performed poorly on food categorization and reasoning tasks due to their undeveloped executive functions skills. Our previous experience revealed that higher levels of food rejection were predictive of lower cognitive flexibility.

To investigate the potential mediating role of cognitive flexibility on the relation between food rejection and categorization abilities, (Experiment 1) a categorization task, and (Experiment 2) a flexible categorization task were proposed respectively to 136 and 100 children. The second experiment required to be conceptually flexible because children had to alternatively categorize the same food in two different categories. It showed that neophobic children's categorization limitations may reflect their inability to flexibly apply their conceptual knowledge (Chapter 8).

First, categorization performance and food rejection were significantly negatively associated. Second, cognitive flexibility assessed through the DCCS and food rejection were also significantly negatively associated. More importantly, a mediation analysis revealed that cognitive flexibility partly mediated the relation between food neophobia and categorization performance (Figure 11).

The results from this first experiment suggest that cognitive flexibility is, indeed, an important component of the relation between food rejection and categorization abilities. The next experiment went a step further and asked children to alternatively associate the same food with two exemplars from taxonomic and thematic categories while ignoring an unrelated food choice. The double selections of correct choices assumed categorical flexibility and should have tested whether neophobic and picky children have difficulties accessing an alternative form of categorization conflicting with a previous form of categorization.

The Double selections performance and food rejection were significantly negatively associated. Again, food rejection and cognitive flexibility were negatively associated. Critically, cognitive flexibility fully mediated the relation between food rejection and categorization performance on the Double selections (Figure 13).

The results of these two experiments suggest that, compared to neophilic and less picky children, neophobic and picky children are more likely to do more food categorization errors because they lack the cognitive flexibility skills to recode the stimuli in order to find a second conceptual relationship. They also suggest that cognitive flexibility is differently central to this relation as a function of the task demands. Indeed, cognitive flexibility fully mediated the relation only when the task explicitly required conceptual flexibility.

The first objective of the thesis was to investigate the role of executive functions on the relations between food rejection and categorization abilities. The hypothesis was that executive functions mediated the relationship. The results described above allows the revision of this hypothesis: highly neophobic and picky children have poor categorization performance through a mediating effect of cognitive flexibility (Figure 14).

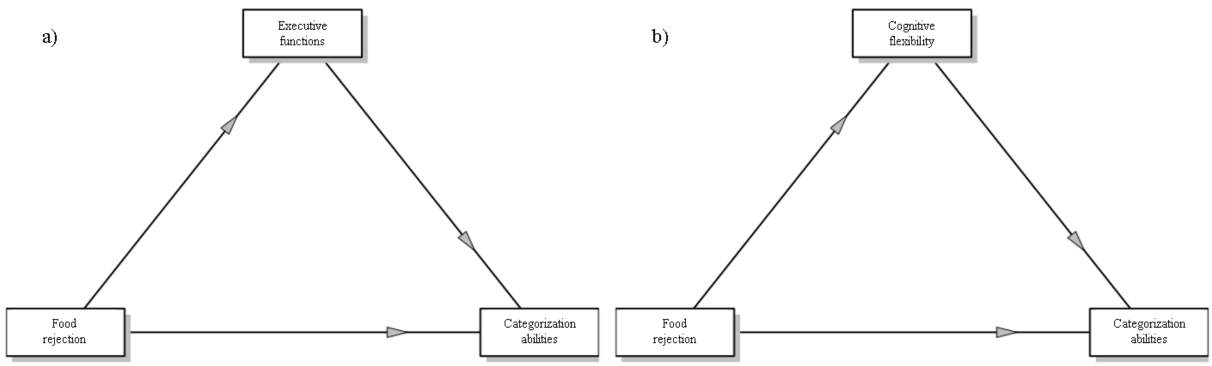

Figure 14. The trifactorial relation among food rejection, executive functions, and categorization abilities. a) Initial hypothesis. b) Revised hypothesis, empirically supported by the results.

The results allow to precise the interpretation of the relation between food rejection and categorization abilities. For some researchers, due to reduced interaction with different food categories, neophobic and picky children end up lacking the conceptual knowledge related to these categories (Harris, 2018; Rioux et al., 2016). In light of our findings, children with high food rejection may also lack the cognitive flexibility needed to understand and identify the relevant conceptual relations in a given context (we saw in Chapter 1 that food knowledge is diverse, involving multiple types or relations, each potentially giving rise to different inferences). Furthermore, if, as our results suggest, food rejection is related to more general cognitive abilities, we can expect neophobic children to also have difficulties in categorization tasks that do not involve solely food stimuli or situations.

This more general perspective also opens up promising practical perspectives. Chapter 1 reviewed the evidence for children's knowledge of different concepts of food from 3 years (when the food rejection behaviors emerge). According to our findings, the children who have more difficulties switching from one category (e.g., taxonomic) to another (e.g., thematic) are more likely to have high food rejection. Therefore, it could be beneficial to teach children about the different categories of food, and not solely that there are healthy and unhealthy foods. Food knowledge does not solely encompass the knowledge of a food being healthy or unhealthy, but also the kind of food itself, the contextual knowledge available from the food, and the eating situations. Children who have difficulties adapting to changes could rely on other aspects of their knowledge of a food to monitor the situation. For instance, if children fail to identify a cheese served, they could rely on their knowledge that the cheese is served with tomatoes for an appetizer and that therefore, it is most likely mozzarella. Being able to totally or in part identify the food, children’s uncertainty should decrease and the likelihood of the food being accepted increased.

9.3. Conclusion

Caregivers face a vicious circle with children who have severe food rejections. Their children reject novel foods and thus do not build knowledge about them. Lack of knowledge may in turn increases the likelihood of foods being perceived as novels and thus rejected. Continuous rejection may discourage caregivers to present the foods the necessary amount of time to promote acceptance.

The present thesis aimed to break this vicious circle using visual cues of food processing. Processed stimuli had been perceived as safer and children were more willing to categorize them as edible substances. However, neophobic children over executed caution regardless if the substances were unprocessed or processed. Nevertheless, these findings open promising avenues of research for using food processing to reduce children's uncertainty and make experiences with novel foods serener.

The thesis also proposed a redefinition of the vicious circle by including monitoring-related cognitive variables (i.e., executive functions). Food rejection was found to be inversely related to inhibition and cognitive flexibility. Furthermore, cognitive flexibility played a mediating role in the relationship between food rejection and conceptual knowledge. Therefore, for children with high food rejection to be able to extract relevant information from learning opportunities, it seems necessary to reduce the monitoring costs.

The findings from the present thesis are crucial for our understanding of children's difficulties to overcome their food rejection. Children highly neophobic and picky are put in distress by situations that could help them build knowledge about foods. Understandably, they prefer to avoid such situations. Furthermore, our results demonstrate that food rejection is not solely related to conceptual knowledge but also executive functions. Given that children's executive functions have been shown to be relatively stable over time, these early characterizations of food rejection might predict or are compatible with later eating health-related problems especially those that have been characterized by executive functions difficulties. Future work should contribute to establishing if children with low executive functions performance and high food rejection are more at risk of later health difficulties, such as obesity or anorexia nervosa.

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LIST OF APPENDICES

Appendix 1: Child Food Rejection Scale (CFRS; Rioux et al., 2017b)

Madame, Monsieur,

Votre enfant est invité(e) à participer à une recherche en psychologie du développement menée par le Laboratoire d'Etude de l'Apprentissage et du Développement (LEAD CNRS) et dirigée par le Professeur Jean Pierre THIBAUT.

Cette recherche a reçu l accord de l inspecteur de la circonscription de l'école, du directeur de l école et de l'enseignant de votre enfant. L'objectif de notre projet est d'étudier les situations qui facilitent l'apprentissage de nouvelles connaissances par les jeunes enfants. Nous comparons plusieurs méthodes de présentation des connaissances pour identifier celles qui permettent le meilleur apprentissage.

N'hésitez pas à poser des questions à notre équipe scientifique voir contacts en bas de page si vous souhaitez davantage d'informations. Seules les personnes qui collaborent à cette recherche auront accès aux données recueillies, et ce dans le respect le plus strict de confidentialité. Les données enregistrées à l'occasion de cette recherche feront l'objet d'un traitement informatisé et anonyme.

Cette étude aura lieu dans l'école de votre enfant pendant son temps scolaire et durera environ quinze minute
Notre équipe vous remercie par avance de votre collaboration.

Prénom et nom de l'enfant :

J'autorise mon enfant à participer à l'étude qui se déroulera dans sa maternelle
O
N
Signatures des parents, le cas échéant :

Pour la partie de l'étude concernant les comportements alimentaires, merci de répondre au questionnaire au verso
Les données recueillies sont exclusivement destinées aux travaux du Centre de Recherche et leur confidentialité est garantie.

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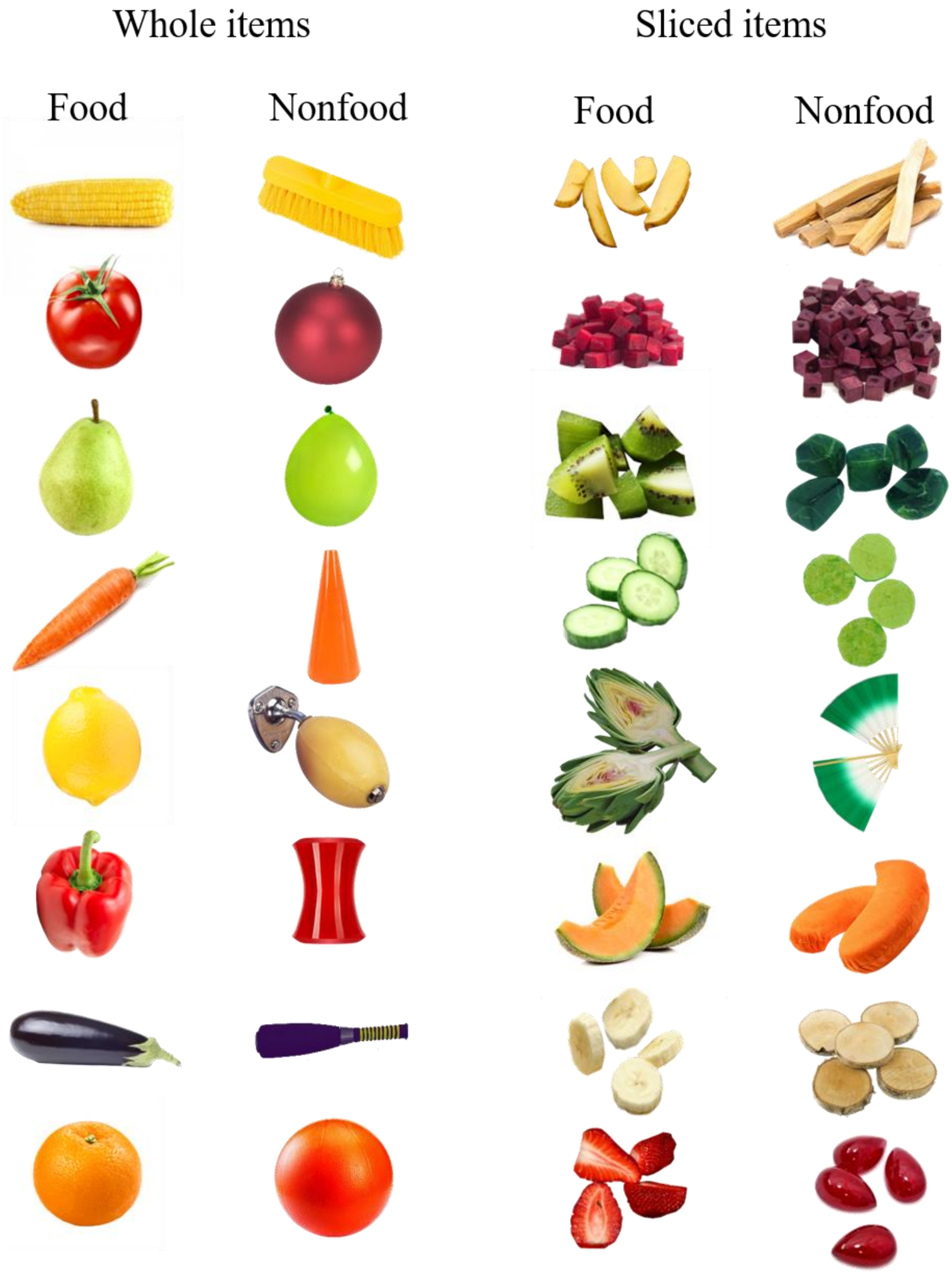
Questionnaire à destination des parents (Cochez la case correspondante) **:**

	Pas du tout d'accord	Pas d'accord	Ni d'accord ni pas d'accord	D'accord	Tout à fait d'accord
Mon enfant refuse de manger certains aliments à cause de leurs textures	☐	☐	☐	☐	☐
Mon enfant fait le tri dans son assiette	☐	☐	☐	☐	☐
Mon enfant rejette certains aliments après les avoir goûtés	☐	☐	☐	☐	☐
Mon enfant peut manger un aliment aujourd'hui et le refuser demain	☐	☐	☐	☐	☐
Mon enfant peut manger certains aliments en grandes quantités et d'autres pas du tout	☐	☐	☐	☐	☐
Mon enfant recherche constamment des aliments familiers	☐	☐	☐	☐	☐
Mon enfant se méfie des aliments nouveaux	☐	☐	☐	☐	☐
Mon enfant aime seulement la cuisine qu'il connait	☐	☐	☐	☐	☐
Mon enfant rejette un nouvel aliment avant même de l'avoir goûté	☐	☐	☐	☐	☐
Mon enfant est angoissé à la vue d'un nouvel aliment	☐	☐	☐	☐	☐
Mon enfant ne goûte pas un nouvel aliment si cet aliment est en contact avec un autre aliment qu'il n'aime pas	☐	☐	☐	☐	☐

Appendix 2: Experiment 1 (Chapter 5) Stimuli Set

Appendix 3: Experiment 1 (Chapter 6) Stimuli Set

Appendix 4: Experiment 2 (Chapter 6) Stimuli Set



Appendix 5: Experiment 1 (Chapter 8) Stimuli Set

Training phase		Test phase		
Tools	Flowers	Vegetables	Fruits	Utensils
Hammer	Water lily	Aubergine	Ananas	Cup
Saw	Wild pansy	Artichoke	Apple	Fork
Scissors		Asparagus	Banana	Glass
Screwdriver		Beet	Kiwi	Knife
Shovel		Bell pepper	Lemon	Pan
Wrench		Carrot	Melon	Plate
		Cauliflower	Orange	Rolling pin
		Celery	Pear	Spoon
		Endive	Strawberry	
		Onion	Water melon	
		Pumpkin		
		Potato		
		Radish		
		Tomato		
		Zucchini		

Appendix 6: Experiment 2 (Chapter 8) Stimuli Set

		Perceptual similarity				Taxonomic ratings				Thematic ratings			
Target	Associates	Mean (*SD*)	*t*-value	*p*-value	*d*-value	Mean (*SD*)	*t*-value	*p*-value	*d*-value	Mean (*SD*)	*t*-value	*p*-value	*d*-value
Lemon	Pear	2.75 (1.16)	-4.80	<.001	-1.07	5.75 (1.37)	5.71	<.001	1.28	3.05 (1.28)	-3.33	.004	-0.74
	Cod fish	1.65 (1.46)	-7.19	<.001	-1.61	2.25 (1.52)	-5.16	<.001	-1.15	5.85 (1.60)	5.18	<.001	1.16
	Natural-flavored yogurt	1.40 (0.82)	-14.17	<.001	-3.78	1.80 (1.15)	-8.54	<.001	-1.91	2.20 (1.47)	-5.47	<.001	-1.22
Chicken thigh	Ham	1.25 (0.44)	-27.68	<.001	-6.19	5.90 (1.12)	7.59	<.001	1.70	3.15 (1.57)	-2.43	.025	-0.54
	Fries	2.40 (1.67)	-4.29	<.001	-0.96	2.95 (1.79)	-2.62	.017	-0.59	6.25 (1.25)	8.04	<.001	1.80
	Ananas	1.85 (1.23)	-7.84	<.001	-1.75	1.50 (0.369)	-16.24	<.001	-3.63	2.05 (1.54)	-5.67	<.001	-1.27
Pickle	Carrot	3.20 (1.70)	-2.10	.049	-0.47	5.05 (1.10)	4.27	<.001	0.96	2.65 (1.46)	-4.13	<.001	-0.92
	Salami	1.30 (0.66)	-18.38	<.001	-4.11	2.95 (1.88)	-2.50	.022	-0.56	6.05 (0.95)	9.71	<.001	2.17
	Mussel	2.55 (1.47)	-4.42	<.001	-0.99	1.60 (0.68)	-15.77	<.001	-3.53	1.65 (0.93)	-11.26	<.001	-2.52
Grated cheese	Camembert	1.35 (0.75)	-15.90	<.001	-3.56	5.45 (1.96)	3.31	.004	0.74	2.95 (1.93)	-2.43	.025	-0.54
	Macaroni	3.10 (1.29)	-3.11	.006	-0.70	2.80 (1.28)	-1.38)	<.001	-4.19	5.90 (1.62)	5.25	<.001	1.17
	Biscuits	1.20 (0.41)	-30.51	<.001	-6.82	1.50 (0.95)	-11.82	<.001	-2.64	1.20 (0.41)	-30.51	<.001	-6.82
Meat-balls	Turkey breast	2.05 (1.23)	-7.06	<.001	-1.58	5.50 (1.47)	4.57	<.001	1.02	3.10 (1.59)	-2.54	.020	-0.57
	Spaghetti	1.80 (1.28)	-7.68	<.001	-1.72	2.95 (1.91)	-2.46	.023	-0.55	6.10 (1.25)	7.50	<.001	1.68
	Cheese for children	1.20 (0.41)	-30.51	<.001	-6.82	1.95 (1.00)	-9.18	<.001	-2.05	1.75 (0.91)	-11.05	<.001	-2.47
Tomato	Cauliflower	1.65 (0.75)	-14.10	<.001	-3.15	5.25 (1.25)	4.47	<.001	1.00	2.90 (1.41)	-3.49	.002	-0.78
	Mozzarella	2.30 (1.56)	-4.88	<.001	-1.09	2.95 (1.54)	-3.05	.007	-0.68	6.30 (1.26)	8.16	<.001	1.82
	Croissant	1.15 (0.49)	-26.05	<.001	-5.82	1.50 (0.61)	-18.42	<.001	-4.12	1.45 (0.69)	-16.62	<.001	-3.72
Pecorino	Petit suisse	1.80 (1.01)	-9.79	<.001	-2.19	5.65 (1.27)	5.82	<.001	1.30	3.00 (1.59)	-2.81	.011	-0.63
	Bread	2.30 (1.42)	-5.36	<.001	-1.20	2.95 (1.88)	-2.50	.022	-0.56	6.30 (1.08)	9.52	<.001	2.13
	Sardine	1.35 (0.59)	-20.18	<.001	-4.51	1.30 (0.47)	-25.68	<.001	-5.74	1.20 (0.41)	-30.51	<.001	-6.82
Nuggets	Steak	3.05 (1.61)	-2.65	.016	-0.59	5.35 (1.73)	3.50	.002	0.78	3.00 (1.38)	-3.25	.004	-0.73
	Ketchup	1.30 (0.66)	-18.38	<.001	-4.11	2.75 (1.94)	-2.88	.010	-0.64	6.30 (1.03)	9.98	<.001	2.23
	Ice cream	1.95 (1.28)	-7.18	<.001	-1.61	1.45 (0.61)	-18.86	<.001	-4.22	1.45 (0.83)	-13.81	<.001	-3.09
Green beans	Pumpkin	1.20 (0.52)	-23.94	<.001	-5.35	5.10 (1.38)	3.58	.002	0.80	3.05 (1.50)	-2.83	.011	-0.63
	Butter	1.70 (1.26)	-8.16	<.001	-1.82	2.25 (1.29)	-6.05	<.001	-1.35	5.00 (1.29	2.81	.011	0.63
	Jam	1.15 (0.37	-34.79	<.001	-7.78	1.70 (0.80)	-12.84	<.001	-2.87	1.35 (0.49)	-24.22	<.001	-5.42
Cheddar	Natural-flavored yogurt	1.35 (0.81)	-14.58	<.001	-3.26	5.15 (0.43)	2.71	.014	0.61	2.00 (1.52)	-5.88	<.001	-1.31
	Buns	2.05 (1.40)	-6.25	<.001	-1.40	2.90 (1.48)	-3.32	.004	-0.74	6.50 (1.05)	10.63	<.001	2.38
	Egg	1.65 (0.88)	-12.01	<.001	-2.69	2.15 (1.09)	-7.59	<.001	-1.70	2.05 (1.36)	-6.43	<.001	-1.44
Sausage	Chicken thigh	2.40 (1.31)	-5.45	<.001	-1.22	6.00 (1.08)	8.31	<.001	1.86	3.20 (1.24)	-2.89	.009	-0.65
	Hot dog bread	2.75 (1.74)	-3.21	.005	-0.72	2.85 (1.93)	-2.67	.015	-0.65	6.30 (1.08)	9.52	<.001	2.13
	Cherry	1.20 (0.41)	-30.51	<.001	-6.82	1.45 (0.61)	-18.86	<.001	-4.22	1.40 (0.60)	-19.44	<.001	-4.35