Implicit and explicit safety evaluation of foods: The importance of food processing

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Abstract

Identifying beneficial foods in the environment, while avoiding ingesting something toxic is a crucial task humans face on a daily basis. Here we directly examined adults' implicit and explicit safety evaluations of the same foods presented with different degrees of processing, ranging from unprocessed (raw) to processed (cut or cooked). Moreover, we investigated whether individual characteristics (e.g., Body Mass Index, food neophobia and hunger) modulated their evaluations. We hypothesized that adults would associate the processed form of a food with safety more than its unprocessed form since processing techniques, which are ubiquitously applied in different cultures, often reduce the toxicity of foods, and signal previous human intervention and intended consumption. Adults (N = 109, 43 females) performed an implicit Go/No-Go association task (GNAT) online, assessing the association between safety attributes and food images differing on their degree of processing; both unfamiliar and familiar foods were used. Then, each food was explicitly evaluated. Results revealed that individual characteristics affected both implicit and explicit evaluations. Individuals with overweight and obesity had a strong and positive implicit association between processed foods and safety attributes, but explicitly rated cooked foods as the least safe overall, this latter result was found in highly neophobic individuals as well. Yet, at the explicit level, when looking at unfamiliar foods only, processed foods were rated safer than unprocessed foods by all participants. Our results are the first evidence that directly highlights the relevance of the degree of processing in food safety evaluation and suggest that thinking of the important tasks humans face regarding food selection enriches our understanding of food behaviors.

Keywords: Food cognition; Go/No-Go association task; Eating behaviors; Inter-individual differences; Control

1. Introduction

Food is certainly one of the most salient and rewarding stimuli in our environment. As omnivores, we need to balance the necessity of gathering a great variety of food to ensure nutritional health against the risks posed by ingesting something toxic and so we engage in hundreds of food choices daily (Rozin & Todd, 2015; Wirt & Collins, 2009). Food is a complex and multi-attribute stimulus and several factors influencing food choices have been well-documented by previous literature, such as energy density, palatability and healthiness of the food (Toepel et al., 2009; Papies et al., 2007; Hare et al., 2011), studied along with differences related to the perceiver (*dietary habits*, Houben et al., 2010; *hunger level*, Hoefling & Strack, 2008; *body mass index (BMI)*, Craeynest et al., 2005; *food neophobia,* Reilly, 2019; *personality* Nederkoorn et al., 2004). However, little is known regarding evaluation of the safety of food, namely whether it is safe to consume or can lead to negative consequences such as poisoning.

1.1. Food processing as a signal of food safety

How we evaluate the safety of food deserves further investigation. The environment in which our ancestors lived and our brains evolved strongly differ from modern Western circumstances (Barkow et al., 1992). Nowadays, we engage in food selection in an environment where the presence of ready-to-eat food and food cues is omnipresent and overwhelming (e.g., Cunnigham & Egeth, 2018; Sanger, 2018). It rarely occurs to us to question whether a food item is safe to eat during a trip to the grocery store where foods are already packaged. Yet, such evaluation had to be made by our ancestors each time a new type of food was encountered (Rozin & Todd, 2015; Wertz, 2019), especially new plant-based foods - an essential component of human diets across evolutionary times (Hardy & Kubiak-Martens, 2016; Ungar & Sponheimer, 2011) - as many plants contain poisonous parts (e.g., cassava root, Cashdan, 1998; see Włodarczyk et al., 2018, for a short review). The importance of identifying edible and non-toxic items appears clear when such capacity is lost as in the case of *pica*, the psychological disorder in which non-edible materials such as metal, soil, pebbles, or clay are frequently consumed, endangering patients' lives, (Sekiya et al., 2018). If pica disorder represents an extreme example, the adaptive problem of finding beneficial food likely shaped our brains in ways that constrain the cognitive processes underlying our food behaviors. One possibility could be to render them sensitive to a range of cues indicating safety and edibility (Wertz, 2019). For instance, infants are selective when inferring edibility from conspecifics' actions, ingesting a particular entity after observing an adult eating it, but not when the adult handles it in other ways without eating it (Wertz & Wynn, 2014).

Diverse cues can signal which foods are safe to eat in a given environment, one of these is food processing. Based on previous work, we define food processing as actions altering the naturally occurring state of the food (e.g., a fruit growing on a tree), such as cutting, cooking or aggregation of different ingredients (Foroni et al., 2013; Rumiati & Foroni, 2016; Foroni & Rumiati, 2017). These are the main, simple processing techniques still being used in most of human societies (e.g., Mombo et al., 2016). Food processing is a prior, and often necessary, step for human food consumption the world over and has been an important part of human life for millennia (Wrangham, 2009). In the *cooking hypothesis*, Wrangham argues that, by providing a significant increase in the net energy gain and softening foods (Boback et al., 2007; Carmody et al., 2011), food processing activities had a key role in human evolution, leading to physical transformations in hominids (e.g., reduction of tooth and gut size and increase of brain size) and freeing our time to engage in other activities rather than chewing and hunting (Wrangham et al., 1999; Wrangham, 2009; Zink & Lieberman, 2016). In contrast, primates spend on average eight hours per day chewing raw foods (Wrangham & Conklin-Brittain, 2003). Importantly, many processing techniques reduce the toxicity of raw food items, lessening the risk of infection and poisoning (Carmody & Wrangham, 2009). For example, cassava root is a staple food in many societies, however it cannot be eaten raw and requires complex processing techniques, such as soaking in water for several days, prior to consumption (Mombo et al., 2016).

Only a handful of studies investigating food evaluation have considered the degree of processing. Yet, they reveal promising evidence that both individuals who are healthy and patients (e.g., Alzheimer dementia) perceive processed foods differently to unprocessed foods (Aiello et al., 2018; Vignando et al., 2018; see Foroni & Rumiati, 2017 for a review). For instance, Coricelli and colleagues (2019a) found significant differences in reaction times, with participants being faster in categorizing processed foods, this behavioral advantage in recognition was supported by differences in the brain responses recorded using electroencephalography. Around130 milliseconds (ms) post-stimulus presentation greater activation in visual areas in response to processed foods was shown, supporting the perceptual relevance of highly rewarding stimuli when compared to less rewarding stimuli (here unprocessed foods; Coricelli et al, 2019a; see also Toepel et al., 2009). In this early time window, the human brain also responds differently to edible (foods) and non-edible (objects and rotten foods) items (around 100 ms post-stimulus onset) (Tsourides et al., 2016). This time is strikingly fast if compared to other effects related to food found in windows between 400 and 800 ms post-stimulus onset such as appetitive conditioning (Blechert et al., 2016). Behavioral data revealed that, in fact, adults and even children see processed foods as human-made objects that bear markers of previous intervention and require less work prior consumption, and see unprocessed foods as more naturally occurring (Foroni et al., 2013; Girgis & Nguyen, 2020). Moreover, developmental data revealed that infants and children might view cues of processing as a signal of food safety. Infants display attenuated wariness behaviors towards novel processed plant foods (e.g., unfamiliar fruits and vegetables cut into pieces) compared to novel unprocessed whole plants with fruits (Rioux & Wertz, 2021). Children assign negative properties (e.g., “This food makes you throw up”) less often to processed foods compared to unprocessed foods (Foinant et al., 2021a). The safety signal likely arises both from the fact that processing techniques often reduce the toxicity of raw foods and because cues of processing reveal that another person has already interacted with a candidate food and has deemed it to be edible.

However, in this line of work, participants were not asked directly about the *safety* of the foods and were always presented with processed foods that differ from unprocessed foods on at least one of the following variables, leading to potential confounds: *food types* (e.g., meat vs. vegetables, Coricelli et al., 2019a; pear vs. star fruit, Foinant et al., 2021a), *caloric density* (e.g., cookie vs. fruit, Girgis & Nguyen, 2020) or *overall shape* and *color* (cut papaya vs. whole plant with fruits; Rioux & Wertz, 2021). Whether individuals perceive the *same* food differently depending on their degree of food processing, remains to be investigated.

1. 2. Implicit and explicit evaluation of food

Food evaluation is known to be influenced by both explicit and implicit factors (Marty et al., 2017; Monnery-Patris & Chambaron, 2020). Explicit evaluations are assumed to influence responses described as conscious or controlled, while implicit evaluations are assumed to influence responses described as non-conscious and uncontrolled (Marty et al., 2017; Perugini, 2005).

Investigations of explicit evaluations of food usually consist of direct self-reports asking participants to rate different dimensions on a scale (i.e., liking, wanting, willingness to pay, frequency of consumption; Roefs & Jansen, 2002; Finlayson et al., 2007; Romero et al., 2018). Individuals’ explicit evaluation of food regarding its caloric content (high vs. low) received most of the attention, with participants often reporting negative evaluations of high-calorie (or high-fat) palatable foods, when compared to the low-calorie (low-fat) unpalatable counterparts (Roefs & Jansen, 2002; Rothemund et al., 2007; Czyzewska & Graham, 2008; Papies et al., 2009; Houben et al., 2010). One of the few studies to investigate explicit evaluation of food regarding its level of processing found that participants view processed foods as more ready-to-eat and requiring less work prior to consumption (Foroni et al., 2013), yet they did not assess *perceived safety* of the different foods. Despite their widespread use, such measures are vulnerable to biases such as the social desirability bias in which participants seek to present a positive image of themselves (e.g., underestimating the liking of junk foods, Cerri et al., 2019; Czyzewska, et al. 2011). Moreover, such measures do not capture well responses influenced by unconscious factors (Monnery-Patris & Chambaron, 2020).

To capture such responses and reduce the social desirability bias, implicit evaluations of food have been studied using indirect behavioral measures, such as the Implicit Association Test (IAT; Greenwald et al., 1998), the Affective priming task (Fazio, 1995) or more recently, the Go/No-Go Association Task (GNAT; Nosek & Banaji 2001). These computerized tasks require fast responses to sequences of stimuli (words, images, etc.) presented for a few hundred milliseconds. The main assumption is that participant responses are facilitated (better accuracy and faster reaction times) if consecutive stimuli, or stimuli which require the same response pattern (i.e., share the same key for response) are closely associated. As with explicit measures, mainly high vs low calorie/fat individuals' evaluations of the foods have been investigated. In sharp contrast with the explicit food evaluation literature, most of the work reports implicit positive attitude towards high-fat palatable foods (Papies et al., 2009; Lamote et al., 2004; Roefs et al., 2005). Indeed, explicit and implicit measures often do not converge, and both measures should be assessed when investigating food evaluation and choices (see Hofmann et al., 2005 for a meta-analysis; Hoefling & Strack, 2008). Regarding implicit food evaluation depending on its degree of processing, using the IAT and controlling for caloric content, Coricelli and colleagues found that participants held a positive implicit association between both processed and unprocessed food and positivity (i.e., words associated with positivity such as joy, peace and holidays; Coricelli et al., 2019b). To our knowledge, this is the only study investigating implicit evaluation of food regarding its degree of food processing, yet the association between food processing and the *safety* attribute was not directly assessed.

1.3 The present experiment

In line with the existing findings, the aim of the present research was to investigate for the first time (i) implicit and explicit safety evaluations of food depending on its degree of processing and (ii) whether individuals' characteristics modulated participants' responses. First, we predicted that individuals would hold a positive implicit association between processed foods and safety, evaluating the processed forms safer than the unprocessed forms. Our primary focus was on implicit association because it rarely occurs to us today to question whether a food is safe to eat or not, but it was a recurrent task over evolutionary time, and therefore, natural selection likely favored cognitive systems sensitive to cues of food safety. Second, we predicted that explicit evaluations would diverge partially from implicit evaluations, because in our modern food environment processed foods are often high in calories/fat and are viewed as "junk foods".

For the implicit evaluation, we used the Go/No-Go association task (GNAT) where participants had to press the spacebar in the presence of a target concept (Go trials) and refrain from pressing it if the presented items belong to other concepts (No-Go trials). The GNAT has considerable methodological advances over the more common IAT (Williams &

Kaufmann, 2012). The primary one is its ability to assess associations between a single concept (e.g., food) and attributes (e.g., safety and toxicity) without having to measure the relative associations between two concepts (e.g., food and non-food) and attributes. The GNAT has been successfully used in several experiments (e.g., Ashford et al., 2018; Buhlmann et al., 2011), notably with food stimuli (Mas et al., 2020; Gerdan & Kurt, 2020; Spence & Townsend, 2007) and shows good psychometric qualities, such as internal consistency and reliability (Bar-Anan & Nosek, 2014, Williams & Kaufmann, 2012). Individual characteristics such as hunger level, food neophobia, dietary habits and BMI were measured because previous work has shown its influence on food evaluation (Coricelli et al., 2019a; Foinant et al., 2021a; Houben et al., 2010; Mas et al., 2020).

Adults completed the GNAT task and explicit ratings task on the same-colored images depicting foods differing only on their degree of processing: (i) unprocessed fruits and vegetables, (ii) the *same* foods cut into pieces and (iii) cooked into a puree. Our focus was on the processing action of cutting foods into pieces because previous work has shown it influences infants' neophobic behaviors (Rioux & Wertz, 2021) and children’s generalization of negative properties (Foinant et al., 2021a; Lafraire et al., 2020). It is also a common component of many more complex food processing techniques and a clear cue of human intervention. In addition, we focused on the action of cooking foods because this technique is more advanced and often efficiently reduces the toxicity of the raw foods (e.g., Mombo et al., 2016, see also Carmody & Wrangham, 2009). We chose fruit and vegetable stimuli because it is an important class of foods with the potential to be poisonous and even deadly to humans (Hardy & Kubiak-Martens, 2016; Henry et al., 2014 Mithöfer & Boland, 2012, Włodarczyk et al., 2018). Importantly, we also chose fruits and vegetables because consumption of these foods is notoriously low and below recommended intakes (Hall et al., 2009). Therefore, it is of crucial importance to shed light on the mechanisms underpinning the evaluation of fruits and vegetables to pave the way towards effective interventions for promoting the adoption of healthy eating behaviors.

2. Materials and methods

2.1. Participants

Participants were 109 Italian adults (43 females) with normal or corrected-to normal vision. Age of the participants was between 18 and 34 years (M = 24.4, SD = 4.0) and their Body Mass Index (BMI, kg/m^2) ranged from 17 to 37 (M = 23.7, SD = 3.9). This sample size was chosen based on a power analysis with pilot participants (with the *powerSim* function from the *simr* package in R; Green & MacLeod, 2016), assuming a small effect size in the implicit Go/No-Go association task (difference in reaction time of 10 ms between experimental conditions, as in studies using similar design, e.g., Mas et al. 2020) and a power of 80%. Data of additional 14 subjects were collected but excluded based on participants' performance on the implicit task (see *data preparation and statistical analysis* section below).

2.2. Procedure

Due to the COVID-19 pandemic, the study was conducted online and participants were recruited through the platform Prolific (Prolific, Oxford, UK; www.prolific.co). Each participant provided informed consent prior to beginning the experiment. The study conformed to the Declaration of Helsinki and was approved by the SISSA’s Ethic Committee. The study lasted approximately 40 minutes and comprised of three separate phases with the following constant order: (a) assessment of the implicit evaluations using a Go/No-Go association task (GNAT); (b) explicit ratings of the food stimuli used in the GNAT; and (c) questionnaires on participants’ characteristics. Stimulus presentation and registration of responses for the GNAT was controlled by PsychoPy 3.0 (Peirce et al., 2019; retrieved from www.psychopy.org) and ran through the online repository and launch platform Pavlovia (www.pavlovia.org) (the GNAT task has already been successfully implemented in online settings, e.g., Ashford et al., 2018). Stimulus presentation and registration of responses for the explicit ratings and questionnaires was controlled by Qualtrics (www.qualtrics.com).

Participants received a compensation of 5 GBP after completion of the study. As this is usual practice in online settings, to ensure participants' attention throughout the study, they were informed they could receive a 1.5 GBP extra payment if they did not answer randomly during the GNAT task (criterion: more than 60% of correct answers), and if they passed two attentional checks added to the questionnaires (i.e., “respond never to this question”).

2.2.1. Implicit evaluations: Go/No-Go association task (GNAT)

The Go/No-Go association task (GNAT, Nosek & Banaji, 2001) was chosen in order to investigate participants’ implicit evaluations of different foods in terms of safety. In this task, participants must (a) respond to target stimuli (Go trials) by pressing the spacebar on a computer keyboard while (b) withholding their response to distractor stimuli (No-Go trials). The response deadline was set to 600 ms with an inter-trial interval of 100 ms consisting of a white screen (see Fig. 1a). Participants were asked to commit as few errors as possible in order to avoid a speed-accuracy trade-off (Zimmerman, 2011), in which participants commit too many errors while trying to respond quickly. These times were selected, based on piloting the task, to balance the need for time pressure while keeping an error rate that could vary between participants. Feedback was given after error trials, with a red “X” appearing below the stimulus for 150 ms.

The GNAT began with four training blocks (see Table 1 and Supplementary Materiel Video S1 for a demonstration of the GNAT task). In the training blocks participants had to respond (i.e., press the space bar) to only one stimuli category (either foods, kitchen utensils, words related to safety, or words related to toxicity respectively in each of the four training blocks). There were 6 trials in each training block. Following the training blocks, participants completed three conditions consisting of two experimental blocks each: Block + and Block - (see Table 1 and SM Video S1). In Block +, participants had to respond to food images and words related to safety and refrain from responding when viewing kitchen utensils and words related to toxicity (see Fig. 1a). In Block -, participants had to respond to food images and words related to toxicity and refrain from responding when viewing kitchen utensils and words related to safety. There were 96 trials in each of the experimental blocks (24 foods, 24 kitchen utensils, 24 words related to safety, 24 words related to toxicity, see Table 1) presented in a pseudo-randomized order, with the constraint that an image trial (food or kitchen utensil) was followed by a word trial (see Fig. 1a). One separate Block + and Block - per condition were created based on our experimental manipulation of the food stimuli namely: raw whole foods (condition P0), raw cut foods (condition P1) and cooked pureed foods (condition P2), see Table 1 for an overview of the GNAT structure. Participants' accuracy and latency to press the spacebar (Reaction Time/RT) reflect the ease to associate the target concept (different food) to the attribute (safety vs toxicity) in the two different blocks. Order of presentation of Block + and Block - within each condition, as well as condition order, were counterbalanced across participants.

Table 1: Overview of the implicit Go / No-Go association task (GNAT)

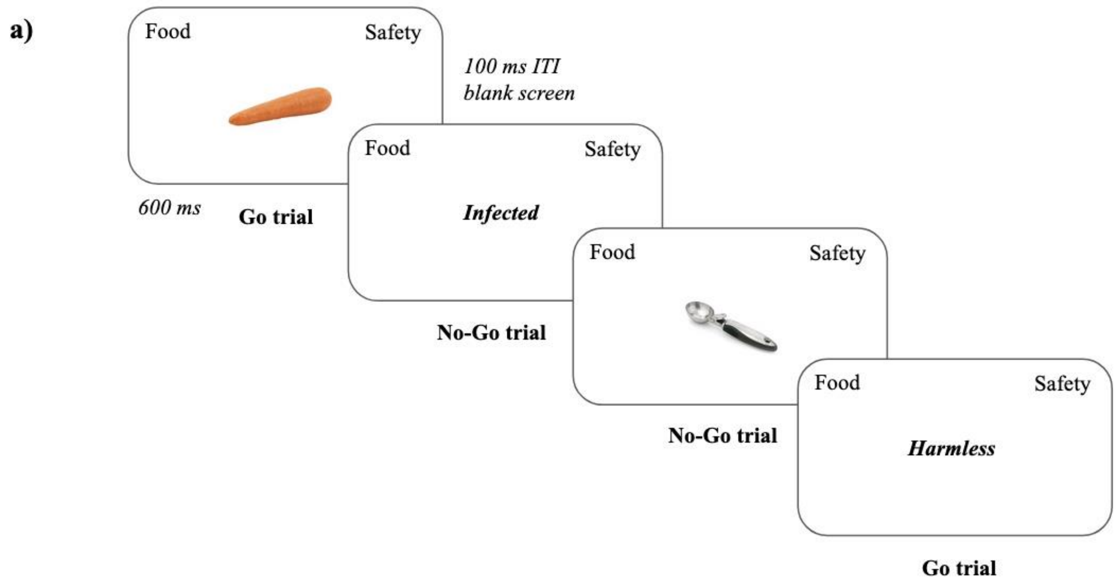
Condition	**Press the spacebar**	**Don’t press the spacebar**	**Number of trials (1:1 ratio)**
Training 1	Food	Utensil	6
Training 2	Utensil	Food	6
Training 3	Safety word	Toxicity word	6
Training 4	Toxicity word	Safety word	6
Condition P0 – Block + (Raw whole foods)	Food or Safety word	Utensil or Toxicity word	96 (8 practice trials)
Condition P0 – Block - (Raw whole foods)	Food or Toxicity word	Utensil or Safety word	96 (8 practice trials)
Condition P1- Block + (Raw cut foods)	Food or Safety word	Utensil or Toxicity word	96 (8 practice trials)
Condition P1- Block - (Raw cut foods)	Food or Toxicity word	Utensil or Safety word	96 (8 practice trials)
Condition P2 -Block + (Cooked pureed foods)	Food or Safety word	Utensil or Toxicity word	96 (8 practice trials)
Condition P2 -Block - (Cooked pureed foods)	Food or Toxicity word	Utensil or Safety word	96 (8 practice trials)

Note. 1:1 ratio indicates an equal number of Go and No-Go trials.

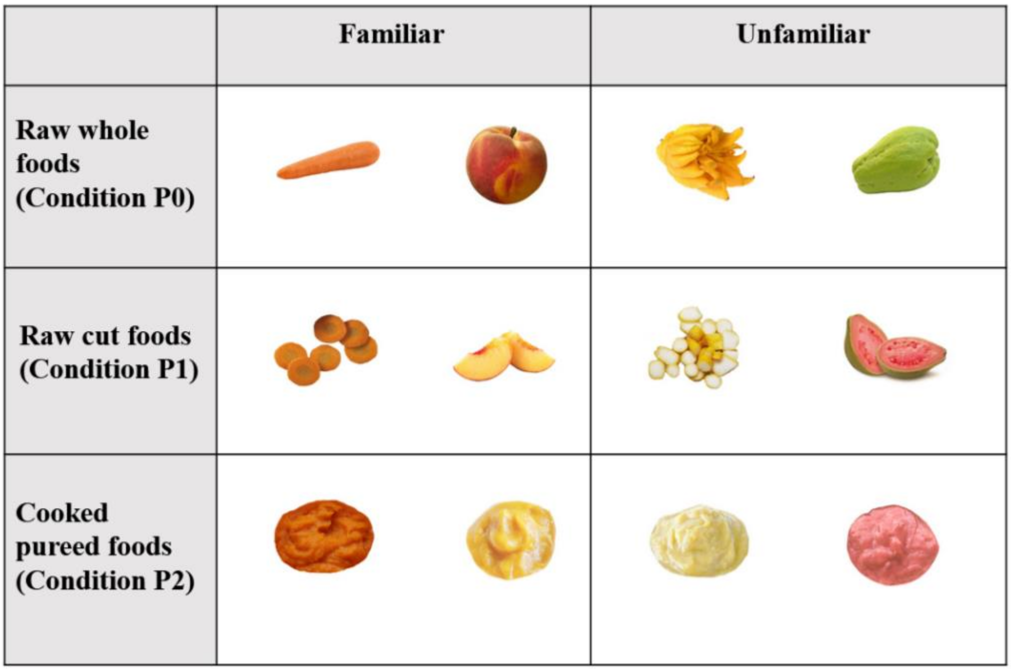
The experimental stimuli for the three different conditions consisted of pictures depicting eight fruits and vegetables, furtherly subdivided in familiar (*carrot*, *tomato*, *peach* and *apple*) and unfamiliar items (*Buddha hand citron*, *pink guava*, *jackfruit* and *starfruit*, see Fig.1b). In condition P0 the fruits and vegetables were presented raw and whole (henceforth whole). In condition P1, they were presented raw and cut into familiar shapes (e.g., slices for tomato, quarters for peach) (henceforth cut). In condition P2, they were presented cooked and pureed, without any container (henceforth cooked). Before each experimental condition began, a short description of the foods depicted in the condition was presented to participants (e.g., 'you will now be presented with pictures of food raw and whole', see SM Video S1). Pictures of 24 different kitchen utensils (8 per condition) matched for overall shape, size and color of the food pictures (e.g., ice-cream spoon, lemon squeezer, pan) were used for distractor picture stimuli. All pictures were color photographs in jpeg-format (1920×1080 pixels), selected from online free from copyright image search, then modified (i.e., cropped) using GNU Image Manipulation Program (GIMP; www.gimp.org) and placed on a white background (see SM Section 1 and Fig. S1 for a complete presentation of picture stimuli). Note that we used a distractor concept (i.e., kitchen utensils that are not obviously dangerous like knives), to keep some difficulty to the task, but the GNAT performs robustly without a distractor concept (Nosek & Banaji, 2001). In addition, the GNAT is not affected significantly by the relatedness of the target and distractor concepts, namely whether they are from related concepts (e.g., fruits and vegetables) or from distant concepts (e.g., foods and clothes) (Nosek & Banaji, 2001).

Finally, we used eight Italian words, four associated to safety (*safe [sicuro]*, *immaculate [immacolato]*, *pure [puro]* and *harmless [innocuo]*) and four associated to toxicity (*infected [infetto], poisoned [dannoso], damaging [avvelenato] and dangerous* *[pericoloso])*. Images and the demonstration video of the GNAT are available on the Open Science Framework (OSF): https://osf.io/snrgk/.

Figure 1: Example of trials in the condition P0 and Block + (Panel a) and example of food stimuli used in the Go / No-Go association task (GNAT) (Panel b). In the Go-trials a whole food [carrot] and a safety-related word [Harmless]; in the No-Go trials a kitchen utensil [ice-cream spoon] and a toxicity-related word [Infected].



b)



Note. In panel a) exemplar trials of the GNAT task in the condition P0 and Block + (raw whole foods presented). Participants had to press the spacebar in the Go trials and refrain from pressing the spacebar in the No-Go trials. Images were presented on the screen for 600 ms and a blank screen was presented for 100 ms as Inter-Trial Interval (ITI). In panel b) exemplar food stimuli used in the GNAT task with the three different degrees of processing.

Stimuli selection was based on the results of a pilot study. A separate set of 29 Italian healthy participants (20 females) aged between 20 and 33 years (M = 26.8, SD = 3.9) were asked to rate 12 pictures of foods depicted in their whole, cut and cooked forms, on the following dimensions: *familiarity* (whole foods), *degree of processing* and *degree of cooking* (cut and cooked foods), *similarity* (between whole and cut/cooked form of the same food), followed, in brackets, by labels at the extremes of the scale:

(a) Familiarity: ‘How familiar are you with the depicted food?’ (‘Very unfamiliar’ [0] – ‘Very familiar’ [100]);

(b) Degree of processing: ‘how prepared (transformed by human intervention for eating purposes) is the depicted food?’ (‘Not at all prepared’ [0] – ‘Very prepared’ [100]);

(c) Degree of cooking: ‘How cooked is the depicted food?’ (‘Not at all cooked’ [0] – ‘Very cooked’ [100]);

(d) Similarity: ‘How similar are the depicted foods?’ (‘Very dissimilar’ [0] – ‘Very similar’ [100]).

For each rating a Visual Analog Scale (VAS) was positioned below the picture which measured 1920 × 1080 pixels. Picture presentation order was randomized across participants. Moreover, participants had to rate 11 words *a priori* related to safety and 12 words *a priori* related to danger on the following dimensions, followed, in brackets, by labels at the extremes of the scale:

(a) Association to safety/danger: ‘How much is the present word associated with the concept of safety/danger?’ (‘Not related to safety/danger at all’ [0] – ‘Very related to safety/danger’ [100]);

(b) Familiarity: ‘How familiar are you with the presented word?’ (‘Not familiar at all’ [0] – ‘Very familiar’ [100]);

(c) Valence: ‘How negative/positive is the present word?’ (‘Very negative’ [0] – ‘Very positive’ [100]).

The number of syllables and word length were also calculated for each word. For the analysis, VAS distances were converted to a scale ranging from 0 to 100, although this was not explicitly displayed to the participants.

We selected food pictures for inclusion in our GNAT that significantly differed in familiarity, with our selected familiar stimuli being significantly more familiar than the unfamiliar foods ($t(3) = 39.02$, $p < .001$). Our selected cooked foods were significantly viewed as more processed than our cut foods ($t(3) = 14.12$, $p < .001$). Our cooked foods were also significantly viewed as less similar to whole foods than our cut foods ($t(3) = 7.65$, $p < .001$). Selected positive words were highly associated with safety and negative words were highly associated with toxicity, with no significant difference in the strength of association ($t(3) = 1.11$, $p = .35$). Moreover, our words differed on valence with the words associated to safety being significantly more positive than the words associated with toxicity ($t(3) = 16.94$, $p < .001$), our words did not differ on familiarity ($t(3) = 1.17$, $p = .33$), nor on word length ($t(3) = 0.87$, $p = .50$) and number of syllables ($t(3) = 0.68$, $p = .55$).

2.2.2. Explicit evaluations: food pictures ratings

After having completed the implicit task, participants rated all the 24 food images presented in the task on different dimensions by selecting their response along a Visual Analog Scale (VAS). The VAS scale was positioned below the images which measured 1920 × 1080 pixels, and picture presentation order was randomized across participants. For the analysis, VAS distances were converted to a scale ranging from 0 to 100, although this was not explicitly displayed to the participants. Participants rated the images of whole foods, cut foods and cooked foods on the following five dimensions: *safety, valence, wanting, healthiness* and *frequency of consumption*, followed, in brackets, by labels at the extremes of the scale:

(a) Safety: 'How safe is ingesting the food represented in the picture?' ('Not safe at all' [0] – 'Very safe' [100]);

(b) Valence: 'How negative/positive is the content of the picture for you?' ('Very negative' [0] – 'Very positive' [100]);

(c) Wanting: 'How much do you want to eat the food represented in the picture at this moment?' ('Don't want to eat it now' [0] – 'Want to eat it now' [100]);

(d) Healthiness value: 'How healthy is the food represented in the picture?' ('Not healthy' [0] – 'Very healthy' [100]);

(e) Frequency of consumption: “How often do you eat the food represented in the picture? (“I never eat this food [0] – I eat this food very often [100]”).

2.2.3. Questionnaires on participants’ characteristics

After having completed the implicit and explicit tasks, participants reported their characteristics (i.e., age, gender, height and weight) and hunger level using a Visual Analog Scale (VAS). Due to the COVID-19 pandemic these characteristics were self-reported by participants, instead of measured in person in the lab, but several studies indicate that in-lab measured and self-reported anthropometric data (e.g., height and weight) are strongly positively correlated and those self-reports can be a valid method of collecting anthropometric data (Bonn et al.,2013; Lassale et al., 2013; Huang et al., 2020; Pursey et al. 2014; van der Laan et al., 2022). For the analysis, VAS distances were converted to a scale ranging from 0 to 100, although this was not explicitly displayed to the participants. Two separate questions regarding hunger level were presented investigating *pre-task hunger level* and *post-task hunger level*, followed, in brackets, by labels at the extremes of the scale:

(a) How hungry were you before beginning the study? (“Not at all [0] – A lot [100]”);

(b) How hungry are you at the moment? (“Not at all [0] – A lot [100]”).

Moreover, participants had to report “How many hours ago did you have your last meal?” by inserting the number of hours.

A questionnaire regarding participants’ dietary habits was then completed; participants had to report whether they had food allergies (i.e., gluten, lactose, nuts, other), food intolerances (i.e., gluten, lactose, sulfites, fructose, other), how would they define their diet (i.e., omnivore, vegetarian, vegan, other) and whether they had other dietary restrictions other than caused by allergies or food intolerances - for example, ones based on personal, ethical or religious reasons. Finally, participants had to fill in the standardized and validated questionnaire investigating novel food avoidance: the Italian translation of the Food Neophobia Scale (FNS) (for the complete set of Italian questions see Proserpio et al., 2016), which consists of 10 statements regarding individual tendencies to approach or avoid unfamiliar foods (exemplar statements: “I like foods from different countries” or “I am very picky”). Participants had to report their agreement on each statement on a 7-point Likert-like scale (“Strongly disagree” – “Strongly agree”). For the analysis, each answer was then numerically coded with high scores indicating high food neophobia (possible range 10-70).

2.3. Data Preparation and Statistical Analysis

Data and scripts used for statistical analysis are available on the Open Science Framework (OSF): https://osf.io/snrgk/. All analyses were performed in the R environment (version 3.6.3; www.r-project.org/). To investigate whether participants hold implicit and explicit associations between processed foods and safety, participants’ answers have been analyzed using a Linear Mixed-effects Model approach (LMM, Bates et al., 2015) using the *lmer* function (*lme4* package; cran.rproject.org/web/packages/lme4/index.html). This method allows to exploit the inter-trial variability by analyzing each data point per participant and allows to investigate the modulation of different factors. Such models are called mixed since they include *fixed* effects which represent population-level effects which should persist across experiments and *random* effects which vary across level of grouping factors (i.e., participants) (Brown, 2021; Meteyard & Davies, 2020).

To investigate implicit associations, we tested separate LMM models with average Reaction Times (RTs) and Error rates as dependent variables, because meaningful information about task performance can be found in both average reaction times and errors due to a potential speed-accuracy trade-off (Nosek & Baniji’s, 2001). To investigate explicit associations, we tested separate LMM models with each Explicit ratings as dependent variables (Safety, Valence, Wanting, Healthiness and Frequency of consumption). In total nine LMM models were tested (see details below). In all LMM models, participants served as a random effect to account for shared variances within subjects (see also Aiello et al., 2018; Coricelli et al., 2019b; for a similar approach). The fit of each LMM model was tested by comparing it to the fit of its null model (containing no predictors) through the AIC (Aikake Information Criterion) values. Furthermore, for the full models, analysis of deviance was first inspected using the *Wald chi square test* and then post hoc comparisons were performed using the *emmeans* function (R packages *car* and *emmeans*). Multiple comparisons were controlled for using the Tukey's method.

2.3.1. Go/No-Go association task (GNAT): Reaction Times (RTs)

Before running the LMM models we checked whether some reaction times (RTs) data should be excluded from analysis. Following Nosek & Baniji’s (2001) recommendations, RTs were examined to determine if any participants had more than 10% trials with responses under 300 ms, as they reflect stimulus anticipation and random responding (Buhlmann et al., 2011), or overall accuracy below 60%. Fourteen participants were excluded based on these criteria, leaving a sample of 109 participants. Next, we removed from analysis the first 8 trials (out of 96) in each of the 6 experimental blocks (Block + and Block - in each condition, see Table 1) as they could be regarded as practice trials. Further, as recommended, erroneous RTs to distractor trials (i.e., trials with kitchen utensils) were not included in the RTs analysis, so that only target trials (i.e., trials with foods) were kept. This deletion occured because the distractors are considered noise. Finally, RTs inferior to 300 ms were excluded from analysis based on previous literature (Buhlmann et al., 2011) and the actual distribution of our data (M = 428.3 ms, SD = 77.7). The task did not register RTs greater than 600 ms, therefore there were no extreme slow RTs to discard.

After the data cleaning step, we computed a first LMM model with the remaining cleaned RTs data as our dependent variable and the following fixed effects: Block (Block + and Block -), Condition (P0, P1 and P2), the five covariates Food familiarity (familiar and unfamiliar), BMI (continuous variable), FNS (continuous variable), Pre-task Hunger levels (continuous variable – henceforth Hunger levels), and Explicit Safety ratings (continuous variable), as well as the interaction between Block, Condition and covariates (see SM Section 2.1.1. and Table S1 for the complete model). A second identical LMM model with Explicit Valence ratings, instead of Explicit Safety ratings, was also tested (see SM Section 2.1.2. and Table S3 for the complete model).

2.3.2. Go/No-Go association task (GNAT): Errors

In order to analyze participants' errors distributions, both target trials (i.e., trials with foods - Go trials) and distractor trials (i.e., trials with kitchen utensils - No-Go trials) were included in this analysis (on the sample of 109 participants and with practice trials excluded). Following Mas et al. (2020) and Gerdan & Kurt (2020), from these trials, the number of *misses* (incorrect responses in Go trials), and *false alarms* (incorrect responses in No-Go trials) were extracted from the data. Overall, a large number of misses indicate low accuracy to the task, while a large number of false alarms indicates a liberal decision bias (e.g., participant tending to press the spacebar for No-Go trials). None of the 109 participants kept for the previous RTs analysis had an overall error rate > 40% (indicating low accuracy, Nosek & Baniji's 2001). Therefore, no further participants were excluded for this analysis.

After this data preparation, a third LMM model with the miss rates as a dependent variable was tested, and the following fixed effects: Block (Block + and Block -), Condition (P0, P1 and P2), the three participant covariates BMI (continuous variable), FNS (continuous variable) and Hunger levels (continuous variable), as well as the interaction between Block, Condition and covariates. A fourth LMM identical to the previous one with false alarm rates as a dependent variable was also tested (see SM Section 2.2. and Table S5 for the complete models).

2.3.3. Food pictures ratings

Explicit ratings (Safety, Valence, Wanting, Healthiness and Frequency of consumption) from the 109 participants have been analyzed by converting the VAS scale ratings to a scale ranging from 0 to 100. One separate LMM model with each of the Explicit ratings as dependent variables was tested, with the following fixed effects: Degree of processing (whole food, cut food, cooked food), the four covariates Food familiarity (familiar and unfamiliar), BMI (continuous variable), FNS (continuous variable), and Hunger levels (continuous variable), as well as the interaction between Degree of processing and the covariates. This analysis resulted in five separate LMM models (see SM Section 2.3. for the complete models).

3. Results

3.1. Implicit evaluations: Go/No-Go association task (GNAT)

3.1.1. Reaction Times (RTs)

Mean participants' Reaction Time (RT) to the task was 438 ms (SD = 54.3), which is similar to previous average reaction times to food stimuli in GNAT tasks (e.g., Mas et al., 2020; Gerdan & Kurt, 2020). The results of our LMM models with RTs in response to target food stimuli as a dependent variable are now described. In the full model Block, Condition, the five covariates Food familiarity, BMI, FNS, Hunger levels, and Explicit Safety ratings, as well as the interaction between Block, Condition and covariates were modeled as fixed effects. The full model had a better fit that the null model (containing no predictors) as shown with a significant drop in AIC ($\chi2(35) = 327.20$, $p < .001$, marginal R2 = .026, conditional R2 = .24). Significant main and interaction effects are presented in Table 2 (see SM Section 2.1.1. and Table S1 for the description of all the main and interaction effects tested in the full model).

Table 2: ANOVA significant results for linear mixed-effect model for participants' Reaction Times (RTs) in the Go / No-Go association task (GNAT) with Explicit Safety ratings.

Effect	χ2(df)	p
Block	63.09(1)	<.001
Condition	175.96(2)	<.001
Safety ratings	10.79(1)	.0010
Condition * Food familiarity	14.25(2)	.0010
Block * Condition * BMI	9.94(2)	.0070

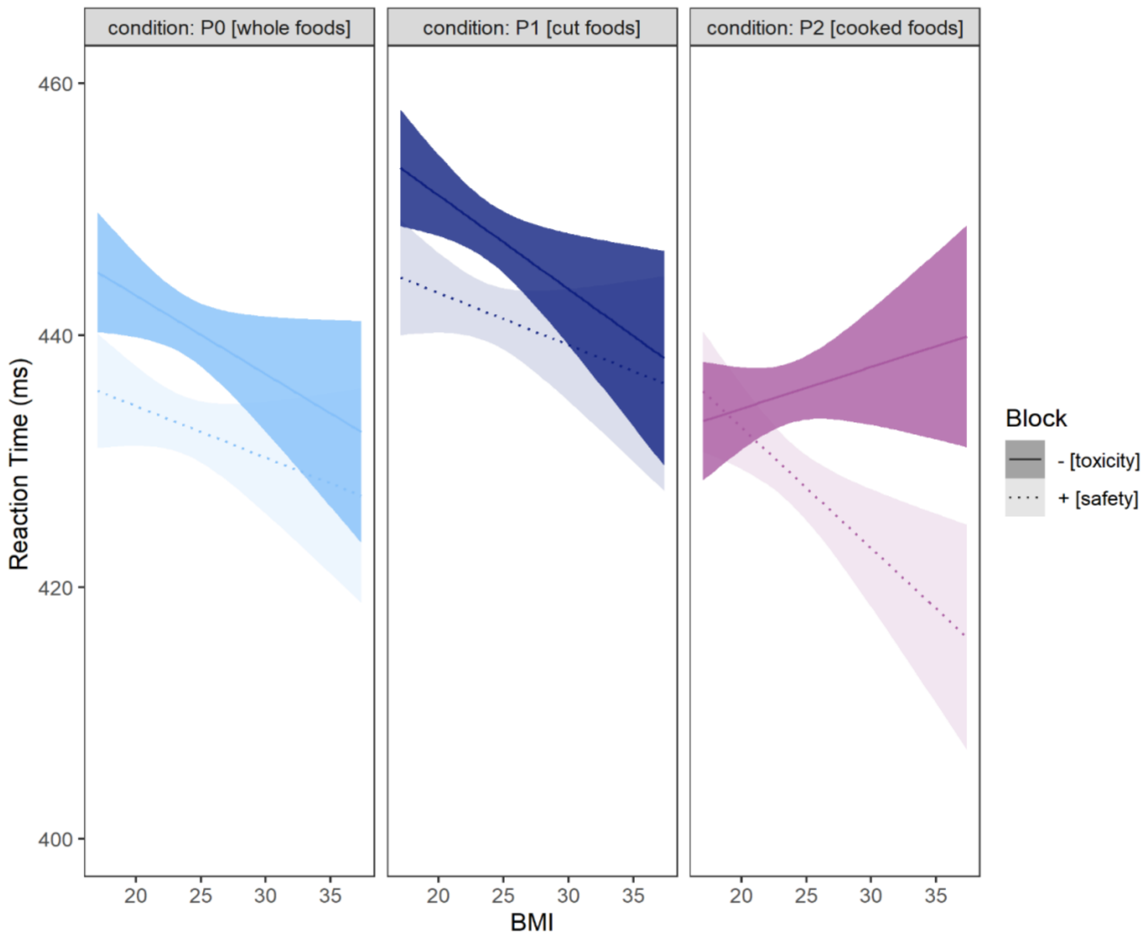
Note. χ2-values for effects using Type II Wald chi-square tests.

In the full model the following main effects were significant: Block Condition and Explicit Safety ratings (see Table 1). The main effect of Explicit Safety ratings indicated that, as participants rated the pictures as safer, they were faster in pressing the space bar in Go trials (i.e., trials with foods) during the GNAT task.

The only 2-way interaction which was significant was the Condition*Food familiarity interaction (see Table 1). Post hoc comparisons revealed that participants were significantly faster in responding to familiar foods compared to unfamiliar foods, only in condition P0 where the foods were whole. Overall, participants were slower in responding to cut foods compared to the other foods (see SM Section 2.1.1. and Table S2 for a full description of the contrasts revealed from the interaction effect between Condition and Food familiarity).

Finally, only the 3-way interaction of Block*Condition*BMI was significant (see Fig. 2). Post hoc comparisons revealed that participants were slower in Block - compared to Block + only in response to cooked foods (condition P2) and as a function of their BMI (b = -1.19, SE = .39, z = -3.06, p = .027). None of the other comparisons were significant.

Figure 2: Participants' Reaction Times (RTs) in the Go / No-Go association task (GNAT) depending on Condition, Block and BMI.



Note. Linear regression lines with 95% confidence intervals. Condition P0: whole foods; Condition P1: cut foods; Condition P2: cooked foods. Block +: food is associated with safety words; Block -: food is associated with toxicity words. In condition P2 only, as their BMI increased, participants associated cooked foods with safety more than toxicity, as they were significantly faster in Block + compared to Block -.

We found a similar pattern of results for our second LMM model with Explicit Valence ratings, instead of Explicit Safety ratings (for the description of all the main and interaction effects tested in the full model see Table S3 in the SM section 2.1.2.).

3.1.2. Errors

Mean participants' miss rate to the task was 17.74 % (SD = 21.07). This indicated that the task was overall easy for the participants. Mean false alarm rate was 9.36 % (SD = 13.03), indicating that overall participants showed a conservative criterion (e.g., tendency to refrain from pressing the spacebar for Go trials). Results with the miss and false alarm rates as dependent variables of the LMM models are now described (see SM section 2.2. for a complete description of the models).

In the full model with the miss rates as the dependent variable, Block, Condition, the three participant covariates BMI, FNS and Hunger levels, as well as the interaction between Block, Condition and covariates were modeled as fixed effects. The full model had a better fit that the null model (containing no predictors) as shown with a significant drop in AIC ($\chi2(23) = 39.47$, $p = .018$, marginal R2 = .046, conditional R2 = .63). Significant main effects are presented in Table 3 (see SM Section 2.2. and Table S5 for the description of all the main and interaction effects tested in the full model).

The main effect of Condition was significant (see Table 3), with participants being more accurate in responding to cooked foods (P2) compared to cut foods ($b = 3.00$, $SE = 1.01$, $z = 2.97$, $p = .0089$). The main effect of Block was also significant (see Table 3), with participants being more accurate in Block + ($b = 2.95$, $SE = .83$, $z = 3.57$, $p < .001$). The main effect of BMI approached significance (see Table 3), indicating that as their BMI increased, participants tended to do less misses (r = -.14, $p < .001$).

In the full model with the false alarm rates as the dependent variable, Block, Condition, the three participant covariates BMI, FNS and Hunger levels, as well as the interaction between Block, Condition and covariates were modeled as fixed effects. The full model had a better fit that the null model (containing no predictors) as shown with a significant drop in AIC ($\chi2(23) = 35.21$, p = .049, marginal R2 = .046, conditional R2 = .23). Significant main effects are presented in Table 3 (see SM Section 2.2. and Table S5 for the description of all the main and interaction effects tested in the full model).

The main effect of Condition was significant (see Table 3), with participants being more conservative (i.e., making less false alarms) in responding to cooked foods (P2) compared to cut foods (b = 2.90, SE = .91, z = 3.20, p = .0042). The 2-way interaction Block*FNS was also significant (see Table 3). In Block -, as their neophobia increased, participants were more liberal (i.e., making more false alarms, r = .013, p = .018). In block +, participants' numbers of false alarms did not change depending of their neophobia levels (r = .021, p = .70).

Table 3: ANOVA significant results for linear mixed-effect models for participants' Errors rates in the Go / No-Go association task (GNAT).

Effect	**$\chi 2$(df)**	**p**
LMM with Misses		
Condition	9.21(2)	.010
Block	12.71(1)	<.001
BMI	3.53(1)	.060
LMM with False alarms		
Condition	10.54(2)	.0051
Block*FNS	4.81	.028

Note. $\chi 2$-values for effects using Type II Wald chi-square tests. FNS = Participants' food neophobia scores.

3.2. Explicit evaluations: food pictures ratings

Mean participants' Explicit Safety rating was 76 (SD = 24), indicating that overall participants judged all foods quite safe to eat. Results with the Explicit Safety ratings in response to food stimuli as a dependent variable of the LMM model is now described. In the full model Degree of processing, the four covariates Food familiarity, BMI, FNS, and Hunger levels, as well as the interaction between Degree of processing and the covariates were modeled as fixed effects. The full model had a better fit that the null model (containing no predictors) as shown with a significant drop in AIC ($\chi 2(14) = 4919.50$, $p < .001$, marginal $R2 = .29$, conditional $R2 = .50$). Significant main and interaction effects are presented in Table 4 (see SM Section 2.3.1. and Table S6 for the description of all the main and interaction effects tested in the full model).

Table 4: ANOVA significant results for linear mixed-effect model for Participants’ Explicit Safety ratings.

Effect	**$\chi 2$(df)**	**p**
Degree of processing	456.28(2)	<.001
Food familiarity	3519.50(1)	<.001
FNS	18.41(1)	<.001
Degree of processing * Food familiarity	1694.44(2)	<.001
Degree of processing * BMI	83.92(2)	<.001
Degree of processing * FNS	187.31(2)	<.001
Degree of processing * Hunger levels	56.19(2)	<.001

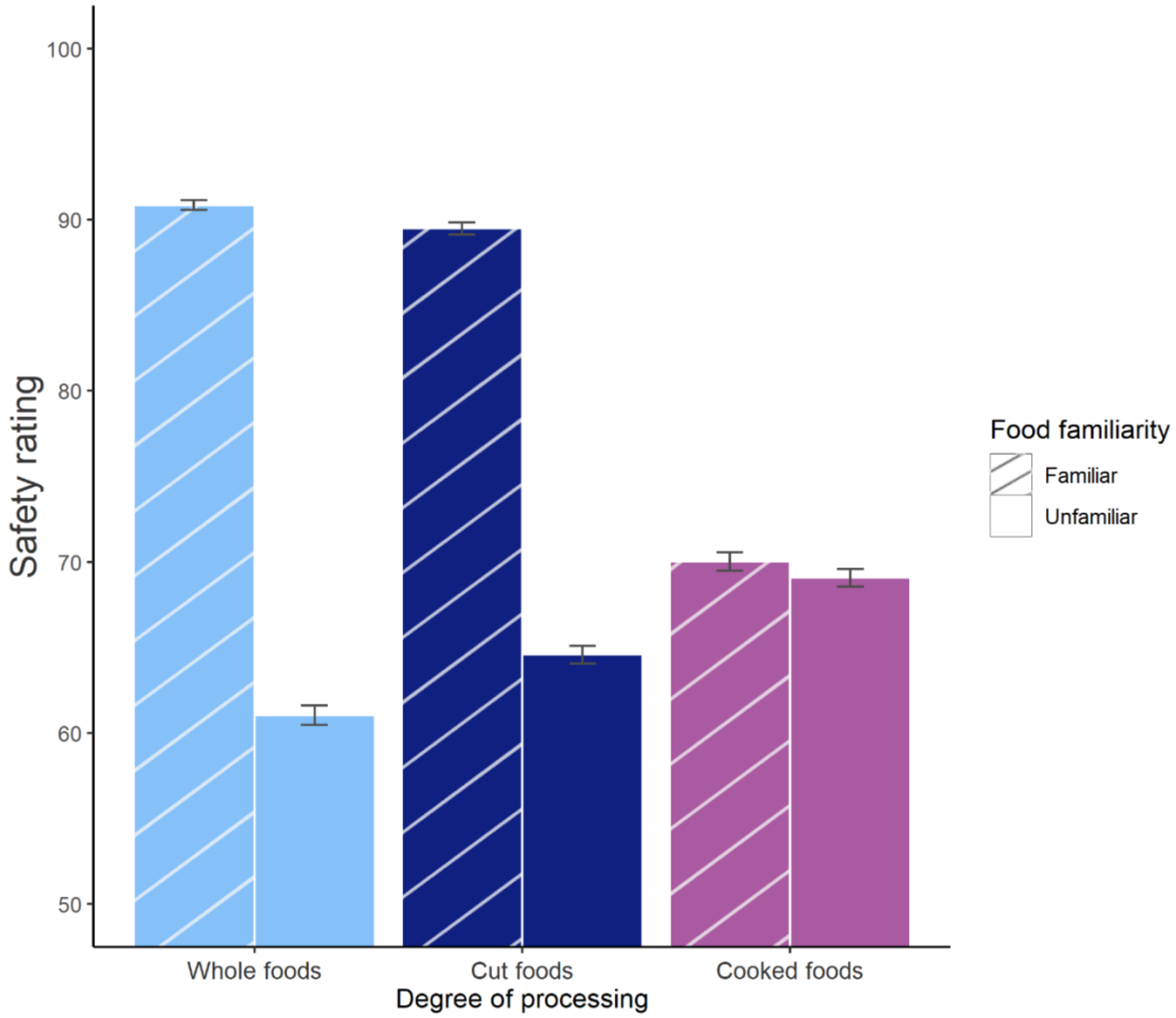
Note. $\chi 2$-values for effects using Type II Wald chi-square tests. FNS = Participants' food neophobia scores.

The following main effects were significant: Degree of processing, Food familiarity and FNS (see Table 4). All the 2-way interactions were significant: Degree of processing*Food familiarity, Degree of processing*BMI, Degree of processing*FNS and Degree of processing*Hunger levels (see Table 4).

Post hoc comparisons revealed that in the 2-way Degree of processing*Food familiarity interaction (see Fig. 3), participants reported familiar foods as significantly safer compared to unfamiliar foods for whole foods (b = 30.06, SE = .54, z = 55.68, p < .001), and cut foods (b = 24.97, SE = .54, z = 45.94, p < .001) but not for the cooked foods. For familiar foods, cooked foods were rated significantly less safe than whole foods (b = -20.99, SE = .53, z = -39.10, p < .001) and cut foods (b = -19.72, SE = .54, z = -36.63, p < .001), that did not differ. On the contrary, for unfamiliar foods, cooked foods were rated the safest (compared to whole foods: b = 8.32, SE = .54, z = 15.39, p < .001; compared to cut foods: b = 4.44, SE =

.54, $z = 8.20$, $p < .001$). Cut foods were also rated safer than whole foods ($b = 3.88$, $SE = .55$, $z = 7.11$, $p < .001$).

Figure 3: Participants' Explicit Safety ratings depending on Degree of processing and Food familiarity.

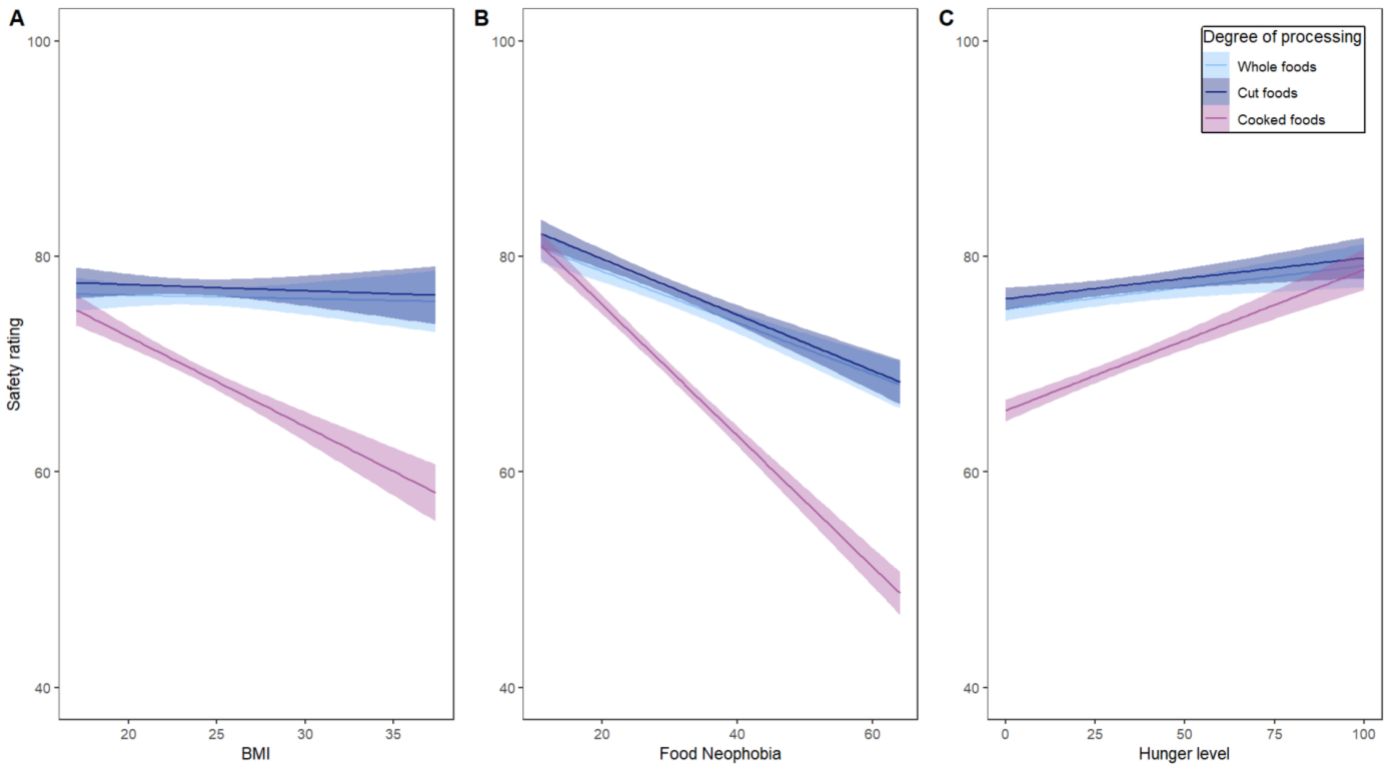


Note. Raw means and standard errors of participants' explicit ratings of safety. For familiar foods, whole and cut foods were rated the safest. For unfamiliar foods, cooked foods were rated the safest. For cooked foods, safety ratings did not differ as a function of food familiarity.

Post hoc comparisons for the other interaction effects revealed that as their BMI increased, participants significantly rated cooked foods as less safe compared to both whole foods (b = -.78, SE = .09, z = -7.87, $p < .001$) and cut foods (b = -.78, SE = .09, z = 7.93, $p <$ .001, see Fig. 4 panel A).

Similar results were found as participants' food neophobia increased (whole vs. cooked food: b = -.36, SE = .03, z = -11.90, $p < .001$, cut vs. cooked food: b = -.36, SE = .03, z = -11.8, $p < .001$, see Fig.4 panel B) and their hunger levels decreased (whole vs. cooked food: b = -.78, SE = .01, z = -5.96, $p < .001$, cut vs. cooked food: b = -.09, SE = .01, z = -6.88, $p < .001$, see Fig. 4 panel C).

Figure 4: Participants' Explicit Safety ratings depending on Degree of processing and BMI (Panel A), Food Neophobia (Panel B) or Hunger level (Panel C).



Note. Linear regression lines with 95% confidence intervals. FNS = Participants' food neophobia scores. High Food neophobia scores indicate high food neophobia (range 10-64, M = 29.51, SD = 12.83). High Hunger levels indicate high hunger before the task (range 10-100, M = 29.13, SD = 28.46).

As the main focus of the present manuscript was to investigate safety evaluations, in SM sections 2.3.2. - 2.3.5 we listed and summarized the results of the other LMM models with, respectively, Explicit ratings of Valence, Wanting, Healthiness and Frequency of consumption as dependent variables of the models with Degree of processing, the four covariates Food familiarity, BMI, FNS, and Hunger levels, as well as the interaction between Degree of processing and the covariates modeled as fixed effects. Overall similar patterns were found across models, with the notable exception that for Healthiness ratings, cooked foods, regardless of their familiarity, were rated less healthy than whole and cut foods. In addition, participants rated more positively and reported to eat more frequently familiar whole foods compared to familiar cut foods, while safety ratings for these two foods did not differ.

4. Discussion

Identifying beneficial foods in the environment is a task we all face daily. A handful of studies revealed that, from an early age, individuals view processed foods more positively than unprocessed foods (Foroni & Rumiati, 2017; Aiello et al., 2018; Coricelli et al. 2019a, 2019b; Girgis & Nguyen, 2020; Foinant et al., 2021a; Rioux & Wertz, 2021), showing the importance of taking into account the degree of processing when investigating human food behaviors. Therefore, the aim of the present study was to expand on this limited line of work and directly investigate, for the first time, whether individuals differently evaluate the safety of a food depending on its degree of processing, both at an implicit and explicit level. Overall, we found pieces of evidence that individuals evaluate the cooked form of a food safer than its less processed forms, albeit with some important modulations depending on participants' and foods' characteristics.

A Go/No-Go association task (GNAT) was employed to investigate the implicit evaluations, given the advantage of this measure compared to other implicit measures (e.g., IAT) in being able to assess a single target concept (Nosek & Banaji, 2001). First, participants' miss error rates showed that, when food was associated with words related to toxicity (Block -), participants were less accurate in their responses, meaning that they were less willing to say the signal (food) was present. The result shows that, overall fruits and vegetables were implicitly associated with a positive attribute. Because we only used low-calorie foods, without comparing them with high-calorie foods, our results can't be directly compared to previous work on implicit attitudes (e.g., Roefs et al., 2005). Instead, our results add to the existing literature which has shown that when compared to non-food (e.g., kitchen utensils), in healthy adults, food overall is associated with positive attributes, even at the implicit level (using the affective priming task, Czyzewska & Graham, 2008; using the IAT, Coricelli et al., 2019b).

Further, and in line with our first prediction, all participants were faster to respond to cooked foods compared to the other foods, made less misses and false alarms in respond to cooked foods and certain individuals evaluated the cooked form of a food safer than its less processed forms. Indeed, as their BMI increased (overall range 17-37) individuals were faster in associating cooked foods with safety (Block +) compared to toxicity (Block -) (see Fig. 2). In sum, individuals with higher BMIs especially associated the cooked form of a food with safety, and none of the individuals associated the less processed forms of a food with higher levels of safety. These results are in line with previous findings showing a greater and faster activation in adult brains in response to processed foods compared to unprocessed foods (Coricelli et al., 2019a), but go further by suggesting that certain individuals represent differently the *same* food depending on its degree of processing, evaluating the processed forms *safer* than the unprocessed forms.

As in Coricelli et al. (2019a), in the present research all participants responded faster to cooked foods, but the finding that only individuals with higher BMIs associated more the cooked form of a food with safety compared to toxicity was less expected. Individuals with overweight and obesity tended to be better at the task resulting in a smaller number of miss errors in our task (i.e., incorrect responses for Go trials regardless of blocks) and previous GNAT studies reported shorter RTs to food images (e.g., Gerdan & Kurt, 2020; Mas et al., 2020; but see Osimo et al., 2019 for an opposite finding). However, we believe that our findings speak against a mere easiness account, because individuals with excess weight and obesity were actually slower to respond to cooked food when it was associated with toxicity (Condition P2, Block -). It is possible that a stronger positive implicit association between safety and cooked foods in certain individuals leads to a higher consumption of these types of foods, resulting in weight gain because in modern circumstances, highly processed foods are often also high in fat and calories. For instance, Marty and colleagues (2017) directly assessed whether implicit attitudes towards foods can predict actual eating behaviors in children and found that they consumed more of a food they previously implicitly rated high on a hedonic level. In our study however, participants' wanting of the foods nor frequency of consumption changed depending on their BMI, but we did not have highly processed foods in our stimuli set. An important outstanding question for future work is then whether an implicit association between safety and processed foods leads to a higher consumption of these particular foods.

After they completed the implicit task, participants completed an explicit rating task on the same images used in the GNAT, given that food evaluation is known to be influenced by both implicit and explicit factors (Marty et al., 2017; Monnery-Patris & Chambaron, 2020). In line with our second prediction that implicit and explicit evaluations would diverge partially, participants rated cooked foods less safe than the other foods, especially people with high food neophobia and people with excess weight and obesity, who had a strong positive association between these processed foods and safety attributes at the implicit level (GNAT RTs results). The explicit results converge with previous literature showing that individuals often report negative evaluations of highly processed foods high in calories when compared to the low-calorie counterparts (Roefs & Jansen, 2002; Rothemund et al., 2007; Czyzewska & Graham, 2008; Papies et al., 2009; Houben et al., 2010).

It is common to find implicit and explicit results, which go in opposite directions (Hofmann et al., 2005; Hoefling & Strack, 2008). Previous literature has explained this phenomenon in light of two models. On one hand, the *Dual Attitudes Model* (Wilson et al., 2000) states that for a given object different evaluations can coexist (i.e., holding an implicit positive evaluation and an explicit negative evaluation for ice cream). On the other, the *Reflective-Impulsive Model* of behavior regulation by Strack and Deutsch (2004) proposes the existence of two separate systems, an impulsive and a reflective one, which produce different behavioral outcomes depending on whether the decision is based on motivational orientations (e.g., food palatability) or based on knowledge (e.g., long-term health consequences). A prediction derived from Strack and Deutsch's model is that, when control resources are reduced (e.g., by time pressure or hunger), the functioning of the reflective system is limited, and impulsive behaviors are increased (Czyzewska et al., 2011; Friese et al., 2008), as would be expected in implicit tasks. In line with the prediction of the *Reflective-Impulsive Model*, in the present study, individuals explicitly rated cooked foods safer as their hunger increased (i.e., when control resources were reduced), converging with their implicit evaluations.

In the present study, it is not surprising that people with high neophobia, overall rated foods more negatively than their counterparts. Neophobia is thought to be a protective strategy against the risk of ingesting potentially poisonous items (Dovey et al., 2008; Lafraire et al., 2016; Reilly, 2019; Rioux, 2019; Rozin & Todd, 2015) and neophobic individuals assign more negative properties to foods compared to individuals with less neophobic disposition (e.g., Foinant et al., 2021a, 2021b). Accordingly, during our GNAT task, neophobic participants were more willing to associate food with toxicity. In general, neophobic individuals tend to show wariness when presented with unknown foods, as these foods may be harmful once ingested, and in the present study, neophobic participants might have rated cooked foods even more negatively, because these foods were overall less familiar to participants (as indicated by the Frequency of consumption ratings). Regarding participants with overweight and obesity, it is possible that these individuals, who might be concerned about weight gain, explicitly rated cooked foods more negatively because nowadays processed foods are often high in calories, and industrialized pureed foods often contain additives (e.g., sugar, salt, conservatives). Thus, we need to consume them in small quantities in order to avoid negative long-term health consequences. Accordingly, our results revealed that all foods were rated less healthy when they were cooked into a puree (as indicated by the Explicit Healthiness ratings), and participants were less willing to eat these foods overall (as indicated by the Explicit Wanting ratings). It remains an open question to what degree our current findings would generalize to other cultures, including non-WEIRD populations (Henrich et al., 2010) in some of which industrialized processed foods are less common and foraging for wild plant-food resources is still practiced.

Nevertheless, the further examination of the explicit ratings, revealed that all individuals rated cooked foods safer than its less processed forms, in a particular situation: when they were confronted with unfamiliar foods. Indeed, for unfamiliar foods, which participants could not recognize easily, participants reported lower values of safety for whole foods compared to cut foods, and then lower values of safety for cut foods compared to cooked foods (see Fig. 3). The familiarity status of each food (familiar vs. unfamiliar) was defined based on the pilot study and validated in the main study, as participants ate more often the familiar foods overall compared to the unfamiliar ones, as indicated by the Frequency of consumption ratings. The result that cooked unfamiliar foods were explicitly rated safer than its less processed forms converges with the pattern found with the GNAT task, showing that under a state of uncertainty, the degree of processing is used as a cue for safety in food evaluation. Further, the degree of processing seems to influence food choices as well, as participants were more willing to eat the foods they rated safer, as indicated by the Wanting ratings that parallels the Safety ratings.

It is important to note that, in the case of familiar foods, cooked foods were actually rated less safe than raw foods. Indeed, whole and cut familiar foods (e.g., whole and cut tomato) were rated the safest by the participants and they rated cooked familiar foods (e.g., cooked tomato puree) less safe. In our modern food environment, it is clear that familiar foods like tomatoes, carrots, peaches and apples are safe to eat. During a trip to the grocery store, it would never occur to us to question the edibility of such familiar foods. On the other hand, because industrialized processed foods might contain unhealthy additives, it is more likely that individuals would question the safety attribute of familiar processed foods. In addition, in the present study participants might have been familiar with the packaging of processed foods, while we presented them with images of plain purees without any container. Accordingly, participants reported that they ate more often the familiar unprocessed foods compared to its cooked counterparts. In sum, it appears that participants rated the safest the foods they knew the best, namely familiar raw foods, but when they were confronted with unfamiliar foods, they used the degree of processing to make safety evaluation.

The association we found in adults of familiar foods with positive properties has been recently found also in children by Foinant and colleagues (2021a) where children would generalize positive properties such as "*gives strength*" to familiar foods and negative properties such as "*gives nausea*" to unfamiliar foods when presented with various types of fruits. Importantly, in this study the degree of processing was also taken into account (though including only cut foods) and the results showed that children significantly generalized more positive properties to cut foods compared to whole foods in the case of unfamiliar foods (Foinant et al., 2021a), converging with our results with unfamiliar foods. Taken together, Foinant and colleagues' along with our findings suggest that when both adults and children have no prior knowledge on foods, cues of food processing afford more positive properties, even at the explicit level.

Future directions and limitations

In summary, the findings from the present study show that adults evaluate, both at the implicit and explicit level, the cooked form of a food safer than its less processed forms, albeit with some important modulations depending on participants' (i.e., BMI, food neophobia and hunger) and foods' characteristics (i.e., familiarity). The results add to the growing literature highlighting the role of cues of processing in the evaluation of food safety (Foinant et al., 2021a; Rioux & Wertz, 2021) and converge with research showing that the degree of processing has a key role in food cognition (Foroni & Rumiati, 2017; Aiello et al., 2018; Coricelli et al. 2019a; Girgis & Nguyen, 2020).

There is much that remains to be investigated however, such as what kind of processing action is needed to trigger a safety signal. In the present study, cooked foods seemed to be the foods most associated with safety (compared to cut foods). It suggests that more advanced processing techniques might be needed to trigger a safety signal. Indeed, these complex techniques (e.g., cooking, soaking in hot water) are often needed to reduce the toxicity of raw foods (Carmody & Wrangham, 2009; Mombo et al., 2016) while cutting a food does not alter its chemical properties. It is important to note that, as a manipulation check, our pilot study confirmed that individuals considered the cooked foods as both more processed and cooked compared to the whole and cut versions of the same food. Remarkably, the procedure of cutting a food is a clear cue of human intervention (Foroni et al., 2013), which could signal intended consumption and modulate *edibility* evaluations (i.e., food vs. non-food). However, it might require further processing actions before being a food actually safe to consume, therefore affecting *safety* evaluations. In line with this idea, Foinant and colleagues (2021b) found that, when children performed a food vs. non-food categorization task, they more often miscategorized cut non-food items as foods, compared to whole non-food items. Future studies can examine further the association between cut foods and edibility, by using in a similar GNAT task, words associated with edibility rather than safety. Another important and related future line of research is to include other types of processing actions and processed foods to investigate further the relative importance of cues of previous human interaction (e.g., cutting, grinding) and chemical alteration (e.g., cooking, pickling, frying) in evaluations of the safety of a food. Finally, it is also an open question, whether our results would hold in younger populations. Childhood is a critical period to examine food evaluation as many foods are initially unfamiliar to children, yet very few studies have investigated implicit food evaluation in this population, probably due notably to the high demands of implicit tasks. Recently a version of the Implicit Association Test (IAT) has been adapted for children as young as four years of age (DeJesus et al., 2020). Therefore, future studies should examine whether children also hold implicit or explicit associations between safety and food processing.

While our current results are consistent with the proposal that cues of processing can act as a signal of food safety, we acknowledge that the present study suffers from several limitations. First, due to the COVID-19 pandemic this research was conducted online, and we therefore relied on self-reports to collect sensitive data such as weight and height. Despite some evidence that self-reports can be a valid method of collecting anthropometric data (Bonn et al.,2013; Lassale et al., 2013; Huang et al., 2020; Pursey et al., 2013), such height and weight data might be especially prone to reporting bias, resulting in a possible underestimation of BMI in our sample (e.g., Pursey et al., 2013) and further testing in the lab is required to assess the robustness of our findings. Due to the online set-up we were also not able to measure participants' actual eating behaviors toward the foods they saw in the task. A behavioral food choice measure must be included in future studies to investigate in detail how individuals' evaluation of food safety predicts actual eating behaviors and to what extent food processing alone can explain cravings for industrialized processed foods as these foods are often both highly processed and high in calories/fat. Second, while the Explicit Frequency of consumption ratings give an indication of participants' familiarity with the foods, we did not directly ask participants to name the different foods. A categorization task performed after the implicit and explicit tasks could have provided a better indication of the role of recognition in safety evaluation. In the present study, we chose cooked pureed foods as the most processed foods to match the visual complexity of the whole, cut and cooked foods (i.e., having all images composed by one single color and element). However, one aspect which might have affected both familiarity and reported frequency of consumption is that rarely pureed foods would be presented without packaging, this is a potential limitation of the study which future studies including a vaster continuum of processed foods could address.

Conclusion

As a first-of-its-kind study, here we present results showing how humans use cues of processing to assign different safety attributes to unprocessed and processed foods. It is of crucial importance to shed light on the mechanisms underpinning the evaluation of foods to identify important mechanisms that can increase acceptance of healthy foods such as fruits and vegetables and pave the way towards effective interventions for promoting the consumption of such healthy food products. This is especially important in populations with high neophobia (mainly children), who have less varied diets, eat less fruits and vegetables and assign more negative properties to these healthy foods (Prosperio et al., 2018, Foinant et al., 2021a, 2021b). Our findings provide a critical first step toward future work that could develop such interventions.

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Authors contributions

CC and CR conceived the original idea of the study, CR designed the experimental task, CC and CR collected the data. CC and CR have conducted data analysis and interpreted the results. CC, CR wrote the manuscript, RIR, CC and CR reviewed and finalized the manuscript.

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