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Eat your vegetables: Exploring food learning cues in 12-month-old infants

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Abstract

Food learning in early life largely relies on social learning. Previous research has shown that infants learn something is edible when they directly observe someone else eating it. However, the role of other forms of food-related social information remains largely unknown. Food processing actions (e.g., chopping, mashing) are essential components of human food behaviors and a ubiquitous part of infants' everyday lives. Here we examined whether infants (i) differentially attend to eating and food processing actions compared to control actions and (ii) learn that novel foods are edible after observing eating and food processing actions performed with them. To do this, we tested 12-month-olds' responses to three different actions: eating, food processing, and a food-irrelevant control. First, we showed infants side-by-side videos of an adult performing two different actions with novel foods across three between-subjects conditions and measured their gaze and pupil dilation with an eye-tracker. Then, we offered infants the novel foods shown in the videos and measured their choices and eating behaviors. Our eye-tracking results indicate that infants differentially attend to eating and food processing actions relative to the control action, and show increased pupil dilation for the control action relative to the two food-relevant actions. When asked to choose which novel food they could eat, infants chose the novel food they saw an actor eat, but only when that eating action was paired with the control action. These findings help identify important mechanisms that increase acceptance of healthy foods early in life.

Keywords: food learning; food-relevant actions; infancy; attention; pupillometry

1. Introduction

Eating a balanced diet rich in healthy foods like fruits and vegetables is essential for good health (Wirt & Collins, 2009). Developing healthy eating habits is especially important in the first years of life because many food preferences are acquired early in development and have a large influence on dietary patterns in adulthood (Luque et al., 2018; Nicklaus et al., 2005). However, as any parent knows, this process can be quite challenging. Food neophobia—the avoidance of novel foods—is well known to occur during early childhood. Young children who are in the process of learning what to eat apart from breastmilk often do not readily accept novel foods, but instead first tend to show avoidance behaviors towards them (Cole et al., 2017; Dovey et al., 2008; Fletcher, et al., 2017; Lafraire et al., 2016; Moding & Stifter, 2016a, 2016b, 2018; Perry et al., 2015). Children are particularly likely to exhibit food neophobia towards fruits and vegetables (Rioux, 2019). As a result, food neophobia can cause a significant reduction of children's dietary variety, which is necessary for normal and healthy development (Falciglia et al., 2000; Woodside et al., 2013). Therefore, it is important to understand how children learn about novel foods in order to identify specific mechanisms that increase acceptance of healthy foods early in life.

1.1. The effect of social information on food learning and avoidance behaviors

Food learning in childhood largely relies on social learning (see e.g., DeJesus et al., 2018 for a review). The existing research has established that children learn that a food is safe to eat when they directly observe social cues that signal edibility (Addessi et al., 2005; Birch, 1980; Laureati et al., 2014). For instance, seeing an adult eating a novel food increases toddlers' willingness to taste this food (Addessi et al., 2005) and school-based interventions where 6- to 9-year-old children observe peers eating novel fruits and vegetables increases children's consumption of these foods and decreases their food neophobia (Laureati et al., 2014). From 6 months of age, infants also learn that a particular entity is edible by observing an adult eat it (e.g., Liberman et al., 2016; Wertz & Wynn, 2014a; 2019) and have expectations about the structure of eating actions (e.g., expecting spoons to be brought to the mouth; Gredebäck & Melinder, 2010; Kochukhova & Gredebäck, 2010). Importantly, infants and young children are selective in the way they use social information to infer edibility (Liberman et al., 2016; Wertz & Wynn, 2014a; 2019). For example, they learn that a particular entity is edible after observing an adult eating it but not when they handle it in other ways (e.g., putting it behind their ear; Wertz & Wynn, 2014a; 2019). Therefore, it seems that food learning in infancy and early childhood is based on a set of specific actions and, as a consequence, not all social information about food has the potential to decrease infants' and children's food avoidance behaviors.

1.2. Cues of food processing as relevant social information about food

The effects of watching someone else eat a food on infants' and young children's food learning and avoidance behaviors has been well studied (see e.g., DeJesus et al., 2018, Rioux, 2019 for reviews). However, the effects of other forms of food-related social information remain largely uninvestigated. One form of social information that deserves further investigation is food processing. Here we define food processing as actions that alter the naturally occurring state of foods (e.g., an apple growing on its tree), such as cutting, grinding, or cooking. These processing techniques have been an important part of human life for millennia (Wrangham, 2009) and are still the main techniques applied to the foods in human societies (e.g., Mombo et al., 2016). Food processing is a prior and often necessary step for human food consumption. For example, foods like breads, stews, cakes, etc. do not exist until naturally occurring foods are processed, sometimes in elaborate ways. Therefore, cues of processing are reliable social signals about what kinds of entities are consumed within the local environment. In fact, adults and children from three years of age view processed foods (e.g., foods cooked and pureed) as human-made objects that bear markers of previous human intervention, while they view unprocessed foods as naturally occurring (Feroni et al., 2013; Girgis & Nguyen, 2020). In addition, adults view processed foods as being more ready to eat than unprocessed foods (Feroni et al., 2013) and children more often miscategorized cut non-food items as foods, compared to whole non-food items (Foinant et al., 2021a). This suggests that adults and young children can use cues of food processing to infer that another person has already interacted with a candidate food and has deemed it to be edible. However, it is not yet known whether infants make this same inference.

Another important aspect of food processing is that many processing techniques reduce the toxicity of raw food items. For example, cassava root is a staple food in many societies, but it cannot be eaten raw and requires complex processing techniques to be consumed without a risk of poisoning (Mombo et al., 2016). It is therefore possible that, in addition to serving as a potential social signal of edibility, cues of food processing also indicate that processed food items are safe to handle, which would decrease avoidance behaviors. Accordingly, children assign negative properties (e.g., “This food makes you throw up”) less often to processed foods compared to unprocessed foods (Foinant et al., 2021b). In addition, infants from 7 months of age are less reluctant to touch novel processed plant foods (e.g., unfamiliar fruits and vegetables picked and cut into pieces) than novel unprocessed whole plants with fruits (Rioux & Wertz, 2021). Furthermore, infants put cut food items in their mouths twice as often as unfamiliar fruits and vegetables that have been removed from plants but are still whole (Rioux & Wertz, 2021). Importantly, in previous studies of food

processing, infants and young children did not witness the acts of food processing directly (Foinant et al., 2021a, 2021b; Foroni et al., 2013; Girgis & Nguyen, 2020; Rioux & Wertz, 2021). Instead, they were presented with foods that had already been processed (e.g., foods cooked and pureed, or cut into pieces) and were able to infer the previous human intervention. Therefore, infants' responses to the food processing actions themselves remain unknown.

Taken together, the existing literature indicates that young children and adults are able to infer that (i) processed foods bear the markers of previous human interaction and edibility and (ii) infants and children view cues of food processing as a signal of food safety. However, two broad questions remain unanswered. The first question is whether infants are particularly attentive to eating and food processing actions when learning about food. It is well established that infants differentially attend to certain types of important stimuli or actions (e.g., Golinkoff et al., 2013). For example, infants prefer to look at someone speaking their own language versus someone speaking a different language and prefer to take a toy from that person (Kinzler et al., 2007). But what about eating and food processing actions?

There are a number of reasons that infants may pay particular attention to someone performing these actions. Infants learn that a particular entity is edible after observing an adult putting it in the mouth, but not when the adult handled it in other ways (e.g., placing it behind the ear, holding it in front of the face and expressing negative affect; Wertz & Wynn, 2014a; 2019) and it is possible that they will also differentially attend to this action. Similarly, infants' attention may be drawn by food processing actions because they may also serve as indicators of edibility, or as indicators of food safety (e.g., Foinant et al., 2021b; Rioux & Wertz, 2021). Therefore, the current experiment tested whether infants differentially attend to eating and food processing actions relative to a control action.

The second question is whether infants perceive social cues of food processing as cues about the edibility of the foods *per se*. Previous results indicate that infants considered cues of food processing as a signal of food safety. For example, Rioux & Wertz (2021) presented 7- to 15-month-old infants with unprocessed whole plants and processed plant foods (e.g., unfamiliar fruits and vegetables cut into pieces) and found an attenuated reluctance to touch and eat processed plant foods compared to whole plants. However, the existing work was not designed to assess eating behaviors, so it is not yet clear whether infants use food processing actions as a cue of edibility.

1.3. The current experiment

The aim of the present experiment is to investigate whether infants (i) differentially attend to eating and food processing actions compared to a control action and (ii) selectively approach and eat novel foods after observing eating and food processing actions performed with them.

To answer these questions, we conducted an experiment with 12-month-old infants using a combination of a preferential looking time paradigm and a choice paradigm. Infants were presented with a split-screen presentation of an adult performing different actions on novel foods (Action Presentation Phase). Infants' gaze was recorded with an eye-tracker to determine (i) which actions they look at longer and (ii) their pupillary changes in response to each display, as infants' attention towards a stimulus can be indexed by increased pupil dilation (Ackermann et al., 2019; Hepach & Westermann, 2016). We tested two types of food-relevant actions—eating and cutting—contrasted with one control action—touching—across three between-subjects conditions. In each condition, infants viewed two actions on the split-screen presentation: 1) eating vs. touching, 2) cutting vs. touching, and 3) eating vs. cutting. The eating action was an adult lifting a novel food to her mouth and consuming a bite of it. The cutting action was an adult chopping a novel food into pieces with a knife (a typical food processing action). The touch control action was an adult holding a novel food with a pair of tongs (to control for the presence of a kitchen tool) and touching the food with her finger. After the Action Presentation Phase of the experiment, infants were presented with the two novel foods shown in the videos. We recorded which novel food the infants subsequently approached and ate (Choice Phase).

Previous research established that infants tend to look longer at and reach for stimuli they prefer (Holvoet et al., 2016; Kinzler et al., 2007; Hamlin & Wynn, 2011). Infants also show increased pupil dilation when they are interested in a stimulus and show learning biases for stimuli that capture their attention (Ackermann et al., 2019; Hepach & Westermann, 2016; Reynolds et al., 2013). Therefore, we predicted that infants would (1) exhibit longer looking times and increased pupil dilation elicited by food-relevant actions (eating and cutting) compared to the control action, and (2) choose and eat the novel food item shown in the food-relevant action videos. Based on the previous research outlined above, we expected that infants would view our eating action as food relevant. Our experimental design allowed us to assess whether infants treat a food processing “cutting” action similarly to a food-relevant eating action or, alternatively, if they treat it similarly to a non-food-relevant touch control action. We focused on the specific food processing action of cutting whole foods into pieces because previous work has shown that infants and children respond differently to cut

foods (Foinant et al., 2021b; Rioux & Wertz, 2021) and it is a common component of many more complex food processing techniques.

2. Methods

2.1. Participants

Participants were 65 healthy, full-term, 12-month-old infants (32 girls; *M* age = 12 months, 9 days, range = 12 months, 0 days – 12 months, 27 days), divided evenly across three independent conditions. This sample-size was based on previous studies using similar methodologies (e.g., Kinzler et al., 2007; Wertz & Wynn, 2019) and based on a power analysis assuming a power of 80% and a large effect size $f = 0.4$, as this is common in infant research (run in G*Power version 3.1, repeated measures ANOVA). We chose this age to include infants with some solid food experience (i.e., already eating solid foods such as raw and cooked fruits and vegetables) and who often engage in social referencing (i.e., looking to an adult when confronted with novel objects or situations and adjusting behavior based on the adult's behavior; e.g., Bazhydai et al., 2020; Schimtow & Stenberg, 2013). In addition, by this age, infants are selective about the actions they use to infer edibility (Wertz & Wynn, 2014a; 2019).

Participants were recruited from a predominantly White population around Berlin, Germany. All infants heard German spoken more than 50% of the time and had no food allergies. Thirty five additional infants were tested but excluded due to (i) fussiness during the test session, (ii) parental interference (e.g., pointing to the screen) or (iii) poor quality data (see SI section 1.2 for details). The study was approved by the local Ethics Committee and parents gave written consent for their child's participation. Parents were compensated with 12€ and infants were given a participation certificate.

2.2. Stimuli

Two types of stimuli were presented to children: black carrots and white parsnips. We chose these stimuli because we assumed they are relatively unfamiliar to infants. Our questionnaire measures confirmed our assumption (see SI sections 1.3 and 2.6 for details). In addition, we chose these food stimuli because vegetables are often among the first foods introduced to infants' diets, but are also the primary targets of children's food avoidance behaviors (Cole et al., 2017; Lafraire et al., 2016).

2.3. Apparatus

Infants were tested in a testing room lit to match the medium luminance of the presentation screen. Infants sat in a baby seat with their parents directly behind them. Parents were instructed not to direct their infant's behaviors during the entire session. Infants were presented with a video-recorded show displayed on a TV screen at 140

cm distance (Samsung LED TV, 50" display, with 1,280 by 1,024 pixel resolution equivalent to 32° by 26° visual angle, and 400 Hz CMR refresh rate). The screen was positioned such that the actor in the videos appeared to be sitting within our presentation stage and presenting the events in person. Participants' gaze was measured with an EyeLink1000 eye-tracker (SR Research Ltd) in remote mode, which is suitable for unrestrained infants. The EyeLink 1000 with its high-speed remote camera provides monocular tracking at a 500 Hz sampling rate. The camera was positioned in front of the infant at a distance of approximately 60 cm (*EyeLink 1000 User Manual*, 2010). After positioning the infant and caregiver in front of the eye-tracker, an experimenter stepped behind a curtain from where the infant and caregiver could be monitored on a video screen and started the experiment.

2.4. Procedure

The testing session consisted of two parts: an Action Presentation Phase using a preferential looking time paradigm presented on a TV screen, and a Choice Phase using a manual forced-choice paradigm. Preferential looking time paradigms have been used successfully with infants for decades, including eye-tracking methods, as have manual forced-choice paradigms (e.g., Aslin, 2007; DeJesus et al., 2015; Hamlin et al., 2007; Hamlin & Wynn, 2011; Golinkoff et al., 2013; Stahl & Feigenson, 2015; Wertz & Wynn, 2014a; Wertz & Wynn, 2019).

The study began with a five-part Action Presentation Phase:

(i) *Calibration*: A five-point calibration was conducted with video stimuli that reliably draw infants' gaze to their center (Schlegelmilch & Wertz, 2019). A calibration was accepted if the calibration error was below 1°. Directly after calibration, seven three-second trials showing neutral light and dark stimuli were presented to assess the individual infant's pupil responses to contrast changes (Schlegelmilch, 2024; see also SI section 2.1). Calibrations were repeated if necessary before the presentation of the food stimuli.

(ii) *First Root Still (1 trial)*: The experimental part began with a central attention grabber (similar to the calibration video, but adapted to the mean luminance of the video presentation) to guide the infants' gaze to the center of the screen. Then, a still image showing piles of the roots on opposite sides of the screen (see Fig. 1, Panel 1) was presented for 15 seconds. Which root (i.e., black carrot vs. white parsnip) appeared on the left vs. right of the screen was counterbalanced across infants. This allowed us to assess if, at baseline, one root type elicited longer looking times than the other.

(iii) *Action Videos (6 trials)*: The show continued with a pair of action videos displayed side-by-side in a split-screen presentation. In the first video, an actor performed one type of action on a root she took from the pile (e.g., eating a parsnip, see Fig. 1, Panel

2). In the second video, the same actor performed another type of action on a root taken from the other pile (e.g., cutting a black carrot, see Fig. 1, Panel 3). Infants watched the two action types repeated three times each. The videos were played one at a time, such that the side of the screen with the video playing (left vs. right) alternated across trials. While one video was playing, the other side of the screen showed a blank grey surface. Central attention grabbers, each presented for 3 seconds, alternated with the action videos. The duration of the action videos was 19 seconds each during their first appearance, including a 3 second phase with the actor looking at the infant before the actions started. During the repeated presentations, this looking phase was removed and the video duration was 16 seconds each. The action pairs shown to infants differed across the three independent conditions (see below). The following were counterbalanced across participants: the side of the screen on which the video appeared first (left vs. right); the action performed on the left vs. right of the screen; the root type used for each action (black carrot vs. white parsnip). This procedure allowed us to assess whether infants' attention was differentially captured by certain actions.

(iv) Action Still (1 trial): Next, the infants were shown a central attention grabber followed by a still image of the two action types concurrently presented side-by-side for 30 seconds (see Fig. 1, Panel 4, see SI section 1.1 for still images of all actions). We included this still image presentation to examine whether infants' forced-choice preferential looking times at the still image revealed increased interest in either of the preceding dynamic action videos.

(v) Second Root Still (1 trial): The show ended with a second presentation of the still image of the root stimuli (see Fig. 1, Panel 5). After 15 seconds, a sound indicated that the trial had ended, and the Root Still remained on the screen for the upcoming Choice Phase. This second presentation allowed us to test whether watching certain actions performed on the roots altered infants' attention toward the roots themselves.

Throughout the Action Presentation Phase, we recorded infants' gaze to determine (i) what they attend to and (ii) their pupillary dilation. Changes in stimulus luminance can present a challenge when using pupil dilation measures. Therefore, following Hepach & Westermann (2016), in order to keep the luminance conditions as constant as possible, (i) the videos were presented on a flat screen monitor using uniform ambient lighting conditions across participants, and (ii) we assessed pupil dilation directly after each action video during the presentation of the central attention grabber.

The study ended with a Choice Phase. At the beginning of this phase, an experimenter, who was blind to the action performed with each root type, emerged from behind a curtain and then reached toward the screen that still showed the two

piles of roots from Second Root Still. The experimenter gave the illusion of picking up one root from each of the piles, presented two real roots to the infant (see Fig. 1, Panel 6; adapted from Kinzler et al., 2007; DeJesus et al., 2015) and asked them which one they would like to eat (as in Wertz & Wynn, 2014a, 2019). The experimenter held the two roots out of infants' reach, and said, in German, "*Hi, do you see these?*" ("*Hallo, Siehst du das hier?*") while making sure infants looked at both roots. Then the experimenter asked infants "*Which one can you eat? Can you show me? Which one can you eat?*" ("*Welches kannst du essen? Zeig mir: Welches kannst du essen?*") in infant directed speech (See Fig 1., Panel 7). At the end of their verbal prompt, the experimenter moved the two roots forward within the infants' reach. If infants were reluctant to choose, the experimenter repeated the questions. Infants' choices were coded as the first root they touched while looking at it (i.e., their first visually-guided reach). Infants' eating behaviors were coded as whether or not they brought the root in contact with their mouth. If infants did not touch either of the roots after 60 s, the session ended. Caregivers were asked to keep their eyes closed throughout the Choice Phase to prevent them from influencing infants' behavior.

There were three between-subjects conditions in which infants watched different pairings of actions during the Action Presentation Phase; the Choice Phase was the same across conditions (see Fig. 1):

(1) *Condition 1 = Eating vs. Touching Actions.* This condition investigated whether infants preferentially attend to eating actions compared to a control action. Infants were shown an actor eating one root stimulus in one video and touching the other root stimulus in the other video. In the eating action video, an actor was seated at a table behind one root type. The actor first greeted the infant, then lifted the root in front of her using a pair of tongs and placed it in her mouth. The tongs were included to control for the presence of a knife in the cutting action video (described below). The actor took two bites, returned the root to the table, and placed her hand next to it. In the touch action video, the same actor was seated behind the other root type. The actor greeted infants, then held the root using a shoehorn (to control for the presence of a tool) and touched the food with her finger. She then moved her hand up and tucked her hair behind her ear to match the low-level features of the eating action (i.e., a hand moving up towards the face, performing a natural-looking action, and moving down again). We used an eating action because infants use this action to learn about edibility (e.g., Liberman et al., 2016; Wertz & Wynn, 2014a, 2019). We used the touch action as a control action that does not indicate edibility but is also a familiar action for infants who routinely see their caregivers interacting with foods and non-food objects. The advantage of using a familiar action as a control compared to an unfamiliar action closely matched for low-level features (e.g., putting the food behind the ear; Wertz &

Wynn, 2014a) is that it removes potential confounds from the preferential looking method (i.e., infants looking longer to unfamiliar actions; see e.g., Aslin, 2007) and from the pupil dilation measure (i.e., infants showing increased pupil dilation to surprising events; Hepach & Westermann, 2016).

(2) *Condition 2 = Cutting vs. Touching Actions.* This condition tested whether infants preferentially attend to food processing actions and view them as a cue of edibility. Infants were shown a video of an actor slicing one root type in front of her with a knife paired with a video of the actor touching the other root type. In the video displaying a cutting action, after greeting the infant, the actor held the root with one hand while cutting slices two times with the knife using her other hand. At the end of the video, the actor tucked her hair behind her ear (to match the low-level features of the eating action). We chose cutting as the food-processing action because it is an important first processing step in many more complex food processing techniques and previous work has shown it affects infants eating behaviors (Rioux & Wertz, 2021). The touch action was the same one described above and, as in Condition 1, the touch action here serves as a low-level familiar control action that allows us to determine whether infants respond differently to food-processing actions (cutting) compared to any kind of contact (touching).

(3) *Condition 3 = Eating vs. Cutting Actions.* In the third condition, we directly compared the two food-relevant actions described above to test whether infants privilege one edibility cue over the other, or if they treat the two actions similarly.

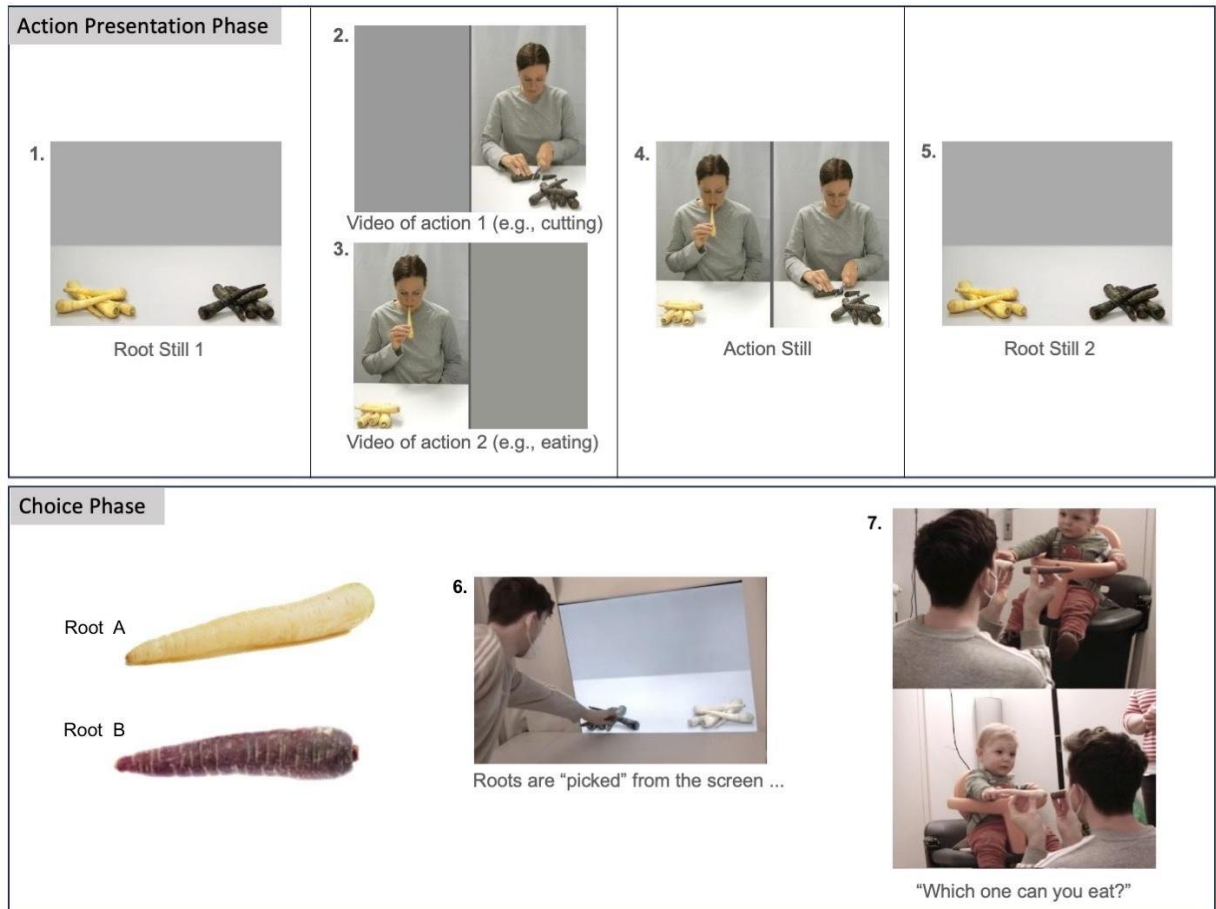


Figure 1. Experimental procedure. After an eye-tracking calibration sequence (not pictured), infants first saw the Action Presentation Phase (top) during which we assessed infants' visual attention and pupil dilation. This phase began with a still image of the two root stimuli (black carrots and white parsnip; Panel 1). Next, infants saw a sequence of alternating side-by-side videos of two different actions (Panels 2 and 3). Each action video was repeated three times for a total of six trials; there were three between-subjects conditions of different action pairings: Cut vs. Eat, Cut vs. Touch, Eat vs. Touch (condition Cut vs. Eat is depicted here). Next, infants were shown one image with stills from both of the action-videos at a time (Panel 4) followed by another still image of the roots (Panel 5). During the Action Presentation Phase, a central attention grabber was shown alternately after each of the videos (not shown here). The final phase of the experiment was the Choice Phase (bottom) in which an experimenter who was blind to the condition acted as if they were "picking" the roots from the screen (Panel 6) and then offered the two real roots to the infants (Panel 7); we assessed infants' reaching and eating behavior.

Parents also completed a battery of five questionnaires, assessing their infant's familiarity with the stimuli, food consumption and feeding practices, food rejection behaviors, and family demographics. Correlational analyses showed that none of the questionnaire measures were systematically related to our DVs of interest (see SI section 1.3 and 2.6 for details).

3. Results

We report the results for our eye-tracking data from the Action Presentation Phase (part (iii), Action Videos) and the Choice Phase. We did not find any significant effects for the Root Stills or Action Stills; those analyses can be found in SI sections 2.3 and 2.4. Video examples, data and analysis scripts are available on the Open Science Framework (OSF):

https://osf.io/2645w/?view_only=c8a76a6a8036436eafc7804da6d9071f

3.1. Prediction 1: Infants will exhibit longer looking times and increased pupil dilation when attending the food-relevant actions compared to the touch control action

In order to test whether infants' attention is captured by food-relevant actions (eating and cutting), we examined infants' looking behavior and pupil dilation during the Action Video portion of the Action Presentation Phase. Our eye-tracking data was assessed at a 500 Hz sampling rate (see section *Apparatus* above). Because in infant studies eye-trackers with a sampling rate of 60 Hz are more common (e.g., Tobii eye-tracking systems), we reduced our data to 60Hz in the pupil-dilation analysis to make it comparable to the results of other pupil dilation studies. Our analyses were performed in the R environment using a linear mixed-effects approach (Bates, et al., 2015). In all models, we used chi-square likelihood-ratio tests (LRT) to test the significance of predictors. LRTs are comparing one current model with a model reduced by the respective predictor with the R-function ANOVA (package car; Fox & Weisberg, 2019). We utilized this same approach with all of our eye-tracking data analyses.

3.1.1. Comparison of proportional looking times during the action videos

In order to test whether infants' attention is captured by food-relevant actions, we measured infants' proportional looking time (i.e., time of gaze on each video divided by video presentation duration) while the action videos were playing in alternation for a total of six trials (three repetitions of each action; see Fig 1, Panels 2 and 3). In the model, infant participants served as a random factor, as well as Trial under the condition of infants. Action (Eat, Cut, Touch), Condition ("Cut vs. Touch", "Cut vs. Eat", "Eat vs. Touch"), Trial (1 → 6), Sex (Male, Female) and Age (continuous variable) were modeled as fixed effects.

The results revealed a significant effect of Action ($\chi^2(2) = 11.75, p = .003$) and Trial ($\chi^2(1) = 19.79, p < .001$). Consistent with our prediction that food-relevant actions would capture infants' attention, infants looked longer toward the eat and cut actions

versus the touch action ($M(\text{eat}) = .90$, $SE(\text{eat}) = .017$, $M(\text{cut}) = .88$, $SE(\text{cut}) = .017$, $M(\text{touch}) = .84$, $SE(\text{touch}) = .017$; Eat vs. Touch, $t = 3.25$ $p = .004$, Cut vs. Touch $t = 2.48$ $p = .040$, see Fig. 2). In addition, infants looking times decreased as the trials progressed ($r = -.22$, $p < .001$). No further effects were significant (see SI section 2.2 for details).

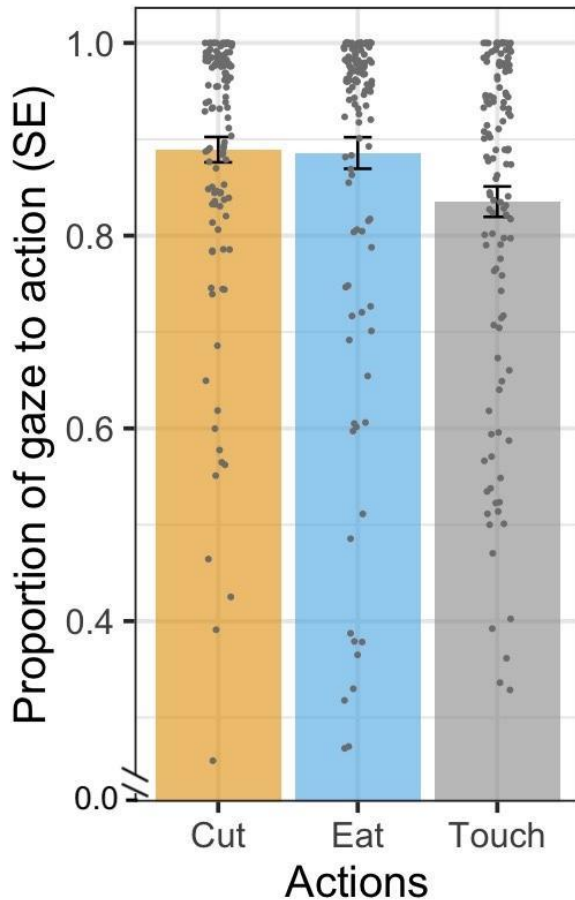


Figure 2. Infants' mean proportional looking time to the different action videos. Infants looked significantly longer at the food-relevant eating and cutting actions than the touch control action.

While watching the action videos, as predicted, infants' attention was captured by the food-relevant actions of eating and cutting. Further, in this analysis, infants treated an eating action and a food processing action (cutting) similarly, despite the fact that our cutting action shares more low-level features with the touch control action.

3.1.2. Effect of action type and trial on infants' pupil dilation

We next examined infants' pupil dilation during the action video sequence in the Action Presentation Phase (see Fig 1. Panels 2 and 3). Changes in pupil size can occur for different reasons, such as luminance differences of the stimuli or cognitive effort

(Hartmann & Fischer, 2014; Steinhauer et al., 2022). Because we were interested in whether infants' cognitive effort differed between the food relevant actions (eating and cutting) and the touch control action, we analyzed pupil dilation data from a point in the procedure that was identical across action types. Specifically, we assessed pupil dilation in a period from 400 ms to 2000 ms after the Action presentation. In this period, gaze had arrived at the screen center where identical attention grabbers were shown for all actions, and when cognitive effort for the shown actions was expected to still affect pupil size (for a similar procedure see e.g., Hepach et al., 2017).

In the model, infant participants served as a random factor, as did video side (left vs. right) and Trial under the condition of participant. Action (Eat, Cut, Touch), Condition ("Cut vs. Touch", "Cut vs. Eat", "Eat vs. Touch"), Trial (1 → 6), Sex (Male, Female), Age, Horizontal and Vertical gaze position and Head distance to the screen (continuous factors) were modeled as fixed effects. Direction of gaze and eye distance can affect pupil size measurement and are therefore suggested to be included as control variables in pupil dilation analyses (Gagl et al., 2011). The dependent variable of pupil dilation was baseline-corrected by its median within individual infants and standardized (Mathôt et al., 2018). We included Trial to gain insight into whether infants show an increase or decrease in cognitive effort, as indexed by changes in pupil dilation, after repeated presentations of each action type. Note that each individual infant only saw three repetitions of an action video, therefore the trial variable includes both within- and between-subjects data.

The models confirmed that viewing the different actions led to differences in pupil dilation, whereas Condition did not contribute to the model and was removed to avoid overfitting. Pupil dilation differed across the actions ($\chi^2(2) = 705, p < .001$). The touch action led to the highest pupil dilation, and the eat action led to the lowest pupil dilation (Eat: 18.4, Cut: 34.4, Touch: 74.6; SE 11.4, all contrasts $p < .001$; see Fig. 5). Infants' pupil dilation also differed across the six trials of the action video sequence ($\chi^2(1) = 14, p < .001$). Pupil dilation increased with the repeated presentations of action type. All control variables contributed significantly to the model (Horizontal gaze position, Vertical gaze position, Head distance, all $p < .05$, see SI section 2.5). There were no further significant effects (all $p > .4$).

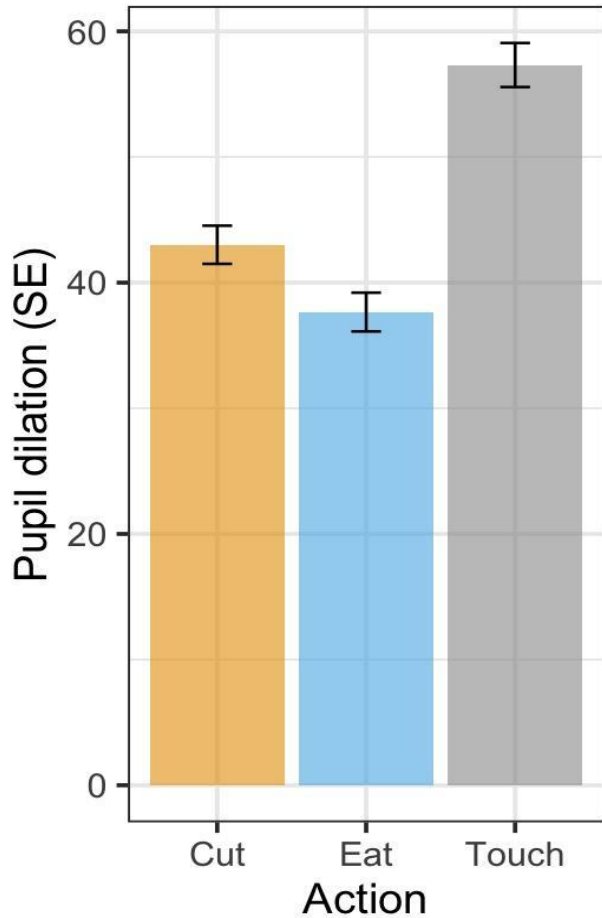


Figure 5. Infants’ mean pupil dilation after viewing the action videos. Infants’ pupil dilation differed across all three action types, and was notably higher for the touch control action than the two food-relevant actions. Note that pupil dilation spread strongly over the session ($SD = 158$), so individual data points are not shown here. The units of pupil size are arbitrary units as common in EyeLink systems.

Our looking time data suggests that infants look longer at the food relevant actions, but the pupil dilation results suggest an overall greater level of cognitive effort after the touch control action.

3.2. Prediction 2: Infants will choose and eat the novel food item shown in the food-relevant action videos

Here we analyzed infants’ behavior during the Choice Phase that followed the Action Presentation Phase. In order to test whether infants prefer novel foods after observing food-relevant actions (eating and cutting) performed with them, we assessed infants’ reaching and eating behavior toward the roots.

3.2.1. Infants' reaching behavior

We first assessed infants' preferences by measuring which root they chose during the Choice Phase. Only valid choices were included in the analysis (see SI section 1.2). Across conditions, preliminary analyses revealed that infants did not prefer one color over the other (24 chose the black carrot vs. 26 chose the white parsnip, Binomial test $p = .45$) nor reaching for one side over the other (21 chose the root on the left side vs. 29 chose the root on the right side, Binomial test $p = .16$). This suggests that infants' choices were not driven by the low-level factors of root color or side. Next, we investigated our main question of whether infants' choices differed across action types within each condition (see Fig. 7).

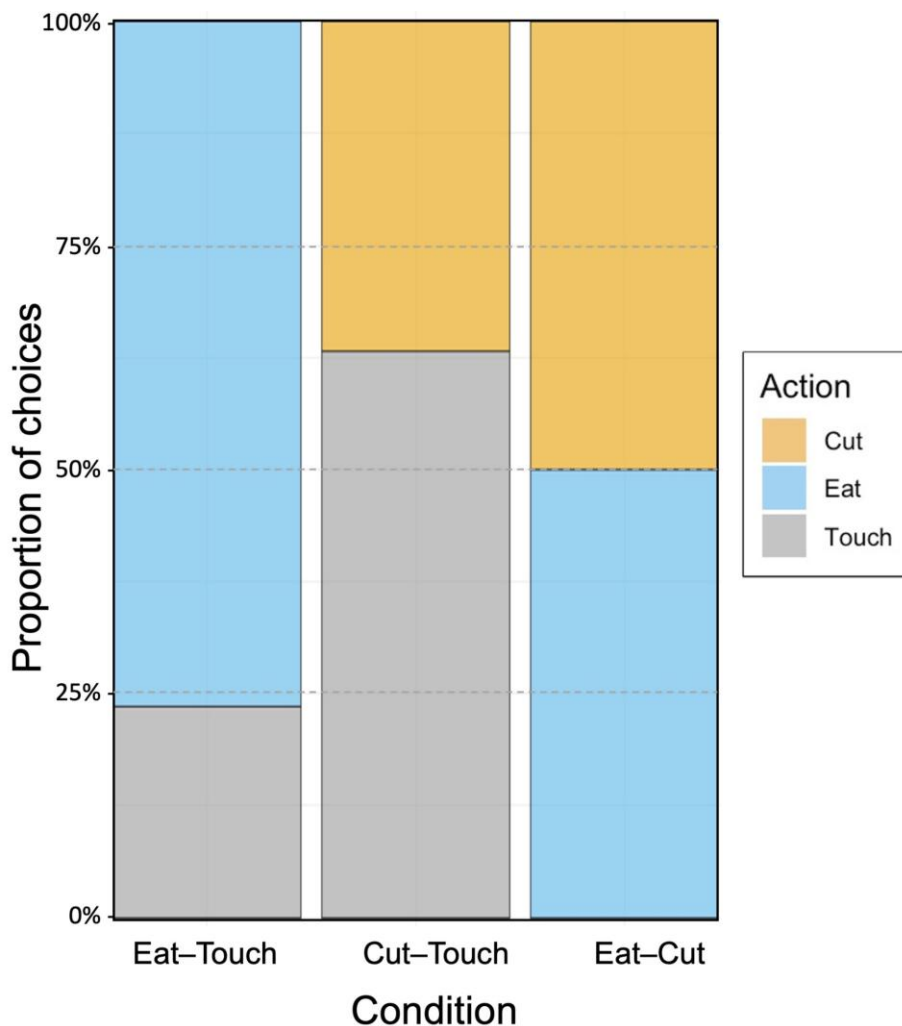


Figure 7: Infants' choices across video pairing condition and action type. Infants showed a significant preference for the root the actor ate in the Eat vs. Touch video pairing condition. No other contrasts were significant.

In the “Eat vs. Touch” condition ($N = 17$), infants chose the root they saw the actor eat significantly more often than the root they saw the actor touch (14 vs. 3; Binomial test, $p = .024$). This suggests that infants view an eating action as an indicator of edibility when it is paired with a touch action, and is consistent with previous findings (e.g., Liberman et al., 2016; Wertz & Wynn, 2014a, 2019).

In the “Cut vs. Touch” condition ($N = 19$), infants showed no preference for the root the actor cut over the root the actor touched (7 vs. 12 Binomial test, $p = .18$). This suggests that infants do not view a cutting action as an indicator of edibility per se when it is paired with a non-food relevant action.

Interestingly, in the “Cut vs. Eat” condition ($N = 14$), infants showed no preference for the root the actor ate over the actor cut (7 vs. 7; Binomial test, $p = 1$), even though they showed a clear preference for the eaten root in the “Eat vs. Touch” condition. It is therefore unclear if this pattern of choice results represents a failure to replicate those results, or if it is an indication that infants view both the eating and cutting actions as indicators of edibility when the cutting action occurs within the context of other food-relevant actions.

3.2.2. *Infants’ eating behavior*

We had planned to assess infants’ eating behavior by measuring which root infants attempted to eat during the choice phase. However, very few infants attempted to eat the roots, preventing us from further analysis (“Eat vs. Touch” condition [$N = 5$]; “Cut vs. Touch” condition [$N = 7$], “Cut vs. Eat” condition [$N = 0$]).

4. Discussion

The aim of this study was to investigate whether 12-month-old infants (i) differentially attend to food-relevant actions (cutting and eating) compared to a control action (touching) presented on a screen, and (ii) selectively approach and eat novel foods after observing the food-relevant actions performed with them. Our results show that 12-month-old infants looked longer at dynamic eating and cutting actions than at the dynamic touch control action, but not when static images of the same actions were presented. Moreover, infants exhibited the greatest pupil dilation in response to the touch control action. After watching the action videos and being asked “*Which one can you eat?*” infants chose the novel food they had seen an adult eat, but only when that eating action was paired with the non-food-relevant touch control action.

4.1. Do infants differentially attend to food-relevant actions compared to a control action?

The current results demonstrate that infants exhibit longer looking times when attending to the food-relevant dynamic actions (cutting and eating) compared to the control action (touching). This pattern supports our first prediction and adds to existing research showing that infants differentially attend to important stimuli or actions (e.g., Golinkoff et al., 2013). Importantly, our findings add a novel dimension to our understanding of social learning about food in infancy: The set of specific actions infants attend to when interacting with food includes food processing actions like cutting. In fact, infants pay similar attention to someone cutting a food and someone eating, which is an established cue of edibility (e.g., Liberman et al., 2016; Wertz & Wynn, 2014a, 2019).

Our results also showed that infants exhibit the greatest overall pupil dilation in response to the touch control action. This finding may seem at odds with our claim that infants preferentially attend to food-relevant actions compared to the control action as infants' attention towards a stimulus has been found to be indexed by increased pupil dilation (Ackermann et al., 2019; Hepach & Westermann, 2016). An alternative interpretation is that infants prefer to attend to food-relevant actions in order to learn about potential food items, but were to some degree puzzled by our touch control action. In fact, previous studies have found that infants can show increased pupil dilation when they observe a surprising event (e.g., someone bringing a spoon to the hand instead of bringing it to the mouth, Gredeback & Melinder, 2010) and that pupil dilation reflect both infants' interest and surprise (Hepach & Westermann, 2016; Jackson & Sirois, 2022). The touch action we used as a control does not indicate edibility per se and infants routinely see their caregivers touching food objects. However, to match the three different actions we tested for low-level features (e.g., length of the action sequences, use of a metal tool), we used a touch action that involved stroking the novel food with one finger while holding it to the table with a metal shoehorn—which might have been particularly unexpected for infants. Future studies could use different control actions that are not food-relevant, and also not surprising.

Our analysis of the pupil data across the consecutive trials revealed interesting differences that could reconcile our looking time and pupil dilation findings (see SI section 2.5). Specifically, pupil dilation evolved differently across trials depending on the action type: dilation for both food relevant actions (eating and cutting) increased over the trials, while dilation for the touch control action did not significantly change across the trials. This may indicate that, even if the touch control action was consistently surprising to infants, food relevant actions were of increasing interest.

Additionally, greater cognitive effort for food-relevant actions as trials progressed might indicate that infants were actively learning about the actions (e.g., Barr, 2010). Future work could investigate whether these results reflect learning or surprise by including additional tasks to assess learning effort (see e.g. Kaldy & Blaser, 2020). In any case, taken together, our pupil dilation and looking time results indicate that infants respond differently to the food-relevant eating and cutting actions than to the touch control action.

4.2. Do infants choose and eat the novel food item shown in the food-relevant action videos?

Although our eye-tracking data shows that infants react to the eating and cutting actions more similarly than the touch action, our choice data suggest that infants may make different inferences about edibility from eating and cutting actions depending on the context in which they occur. Infants viewed the eating action as a cue that a novel food was edible when it occurred in the context of the touch control action, replicating previous results (e.g., Liberman et al., 2016; Wertz & Wynn, 2014a, 2019). In contrast, although infants' visual attention was captured by the cutting action, our choice data suggest they did not view this action as a cue that this food was edible when it occurred in the context of the touch control action. One possible explanation is that infants' attention is captured by food processing actions but cues of processing are weaker cues of edibility than eating actions. In this case, similar designs but with more repetitions of each action might reveal that infants use cues of food processing to make edibility inferences as well. However, when the eating and cutting actions were paired, infants also no longer reliably chose one novel food type over the other, suggesting that context may play a role in how infants make edibility inferences from eating and cutting actions.

Future studies will be necessary to understand the precise role that food-processing actions like cutting play in food learning in infancy. Specifically, future work could investigate whether food processing actions indicate edibility per se or something more like safety. Cutting a food is a clear signal of previous human intervention and is interpreted as such by children and adults (e.g., Foroni et al., 2013, Girgis & Nguyen, 2020). It can also signal intended consumption and modulate edibility evaluations (i.e., whether an item is a food vs. non-food). For example, Foinant et al. (2021a) found that when 4- to 6-year-old children performed a food vs. non-food categorization task, they were more likely to miscategorize cut non-food items as foods than whole non-food items. However, a food that is cut into pieces might require further processing before being actually safe to consume (e.g., cassava roots are staple foods in many African countries but have to be cooked to be safely consumed). It is possible that more advanced processing techniques like cooking, which actually change a food's chemical

properties and decrease their potential toxicity (while cutting does not) might be needed to reliably signal edibility.

A caveat to our choice results is that we were unable to assess infants' eating behaviors because very few infants attempted to eat the novel food stimuli they had chosen. Previous work successfully assessed infants' eating behavior in a choice phase using dried fruits (Wertz & Wynn, 2014a; 2019), so it is plausible that infants' lack of eating in the current study was due to the particular novel food stimuli we chose. We used white parsnips and black carrots in order to have foods that were obviously unprocessed, unfamiliar to infants, and could be both eaten and cut. However, infants may have been reluctant to put these root vegetables in their mouths because they were hard and did not smell particularly appetizing (unlike fragrant dried fruit). Future studies attempting to measure infants' eating behavior could use different unfamiliar food stimuli.

4.3. Limitations and future directions

One potential limitation of our study is that our attempt to closely match our three action types may have made them seem unusual to infants. For example, we included an artifact in all three actions such that the actor first lifted the root with tongs in the eating video, cut the root with a knife in the food processing video, and held the root still with a shoehorn in the touch control video. While the knife was necessary for the food processing video, it is possible that the presence of an extraneous artifact in the eating and touch action could have been surprising to infants. Our data suggest that it does not seem to be the case for the eating actions—infants' looking times and pupil dilation were similar across the eating and cutting videos. However, it may explain infants' longer looking times and greater pupil dilation during the touch control action videos. Even if this is the case, it suggests that infants were responding to a semantic interpretation of the videos that allowed them to evaluate the plausibility of each action type, rather than lower-level features.

Another limitation of the current study was that, during the Action Presentation Phase of the experiment, the same actor appeared twice on the screen (i.e., performing one action on the left and another action on the right side of the screen). We chose to have the same actor on all the videos to avoid a potential confound of preference for one person over the other. It might have been surprising for infants to see the same actor who was alternating in the action videos then duplicated in the action still image. However, additional follow-up analyses of infants' gaze shifts did not indicate particular attention to the actors' duplicated faces (see SI section 2.3.2).

In the current experiment, we chose cutting a novel food into pieces as our food-processing action because previous work has shown that infants and children behave

differently toward cut foods (Foinant et al., 2021a, 2021b; Rioux & Wertz, 2021). Future studies can explore other types of processing actions, including more complex food processing techniques like cooking. Another important question for future research is whether the communicative intent of the person performing the actions is necessary for infants to learn about them. In our study, the adult greeted and made eye-contact with the infants before performing the action, which are ostensive signals of communication. Ostensive communication serves the functions of social information exchange and transmission of cultural knowledge during development and infants expect information to be object-centered and generalizable in ostensive contexts (sometimes referred to as natural pedagogy, Csibra & Gergely, 2009; Egyed et al., 2013; Gergely & Kiraly, 2019). On the other hand, infants often passively observe adults and peers eating and processing foods in their daily routine, so it might be that even in non-ostensive contexts (e.g., Kline, 2015) infants use others' actions to learn about food.

Finally, it is an open question from which social partners infants learn best what to eat. Infants make social inference based on what they see others eat (e.g., Liberman et al., 2014, 2021), but the impact of social status on food learning in infancy is largely unknown. Studies on children's learning from testimony (i.e. others telling them facts about new objects) has shown that children do not treat all informants equally. Instead, they tend to trust more the information provided by familiar over unfamiliar people, reliable over unreliable, experts over non-experts or nice over mean (Wood et al., 2013; Zmyj et al., 2010). Yet, this line of research has mostly been conducted with non-food stimuli and with school-age children and the handful of studies investigating infants and toddlers's food selection based on others' testimonies or actions has revealed mixed findings. For instance, after watching either a stranger or a familiar adult eat an unfamiliar food, 18- to 30-month-old children accept to eat that food (Addessi et al., 2005; Wertz & Wynn, 2014a, 2019), while in another study, 12-month-old infants prefer to learn from an in-group vs. an out-group member (Shutts et al., 2009). Future studies could therefore investigate who has the most influence on infants and toddlers' food selection (e.g., familiar model over unfamiliar, in-group over out-group, etc.).

4.4. Conclusion

The present work investigated the actions infants rely on to learn what to eat. Previous research has shown the influential role of eating actions for guiding infants' food selection (Edelson et al., 2016; Harper & Sanders, 1975; Wertz & Wynn, 2014a; 2019) and our results demonstrate that infants pay similar attention to eating and food processing actions. However, our choice results suggest that infants may make different edibility inferences from eating and processing actions depending on the

context in which these actions occur. The strength of the present work is in using converging measures to gain a fuller picture of the cognitive mechanisms underlying infants' food learning. Our findings can help identify important mechanisms that increase the acceptance of healthy foods early in life.

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Supplementary references

1. Supplementary Methods

1.1 Stimuli (still images of the action)

The first part of the testing session was the Action Presentation Phase during which we assessed infants' visual attention and pupil dilation. This phase began with a still image of the root stimuli. Next, infants saw a sequence of alternating side-by-side videos of two different actions. There were three between-subjects conditions of different action pairings: Cut vs. Eat, Cut vs. Touch, Eat vs. Touch. Next, infants were shown a still image of the two action types presented side-by-side followed by another still image of the roots. Still image of the actions showed the goal of each action (e.g., root in the mouth, knife cutting the root, finger touching the root), see Figure S1 below for a still image of the three actions.

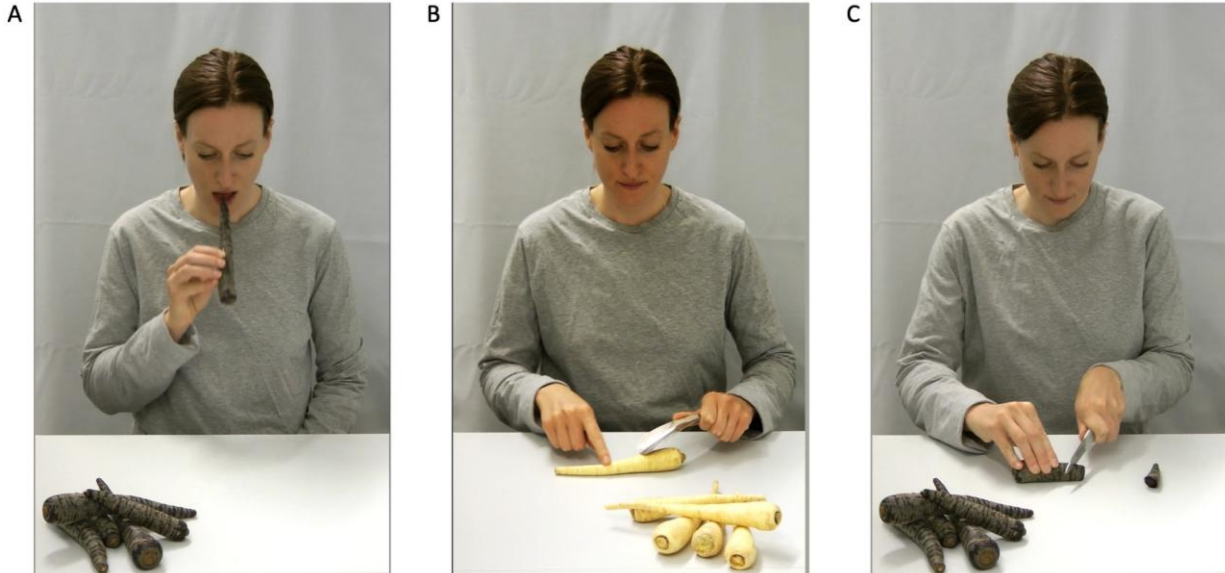


Figure S1. Examples for the still of the action videos. Eating action (A), touching action (B), and cutting action (C) were combined side by side as pairs identical to the preceding action-presentation videos. Action combinations were balanced for root color and side.

1.2 Data exclusion criteria and reliability coding

In order to test whether infants' attention was captured by food-relevant actions, we recorded (i) infants' gaze with an eye-tracker during the Action Presentation Phase of the experiment (DVs : proportional looking time to the different types of action videos, preferential looking at image stills, pupil dilation affected by action videos) and (ii) which of these two novel roots infants subsequently approach and eat during the Choice Phase (DVs: manual choice, eating behavior).

Action Presentation Phase

First, research assistants who were blind to the hypotheses of the study evaluated the videos of the testing sessions to ensure that (i) infants watched critical phases of the Action Presentation Phase and (ii) parents did not interfere with their infant during the testing session. For a given trial of the Action Presentation Phase, if infants did not watch the trial or parents interfered during that trial, it was excluded from further analysis. Two criteria needed to be met to consider that an infant had watched a trial:

- 1) The infant looked at the video during the important part of the action. For the cutting action it was when the actor was cutting two slices with the knife - from the point the knife first touches the root to when the knife begins to be lifted away from the root at the end of the second cut. For the eating action it was when the actor was bringing the root to her mouth and chewing it - from the point when the mouth first closes on the root until the root is brought away from the lips after the last bite. For the touching action it was when the actor was touching the root twice with her finger - from the point when the actor's finger first touches the root until her finger begins to be lifted away from the root after the second touch.

- 2) The infant watched the majority of the action video (from when the actor is saying hello to when she looks down at the end). If the infant briefly looked away it was still acceptable.

Regarding parental interference, we considered that the parent interfered during the trial if one of the following situations happened:

- 1) The parent turned their infant's head and body in the direction of the screen.
- 2) The parent said to their infant to look at the screen or pointed to the screen.

If the parent soothed their infant because the infant started to show signs of distress, without noticeably drawing away the infant's attention from the screen it was considered as acceptable.

After applying the trial exclusions, only infants who looked at at least one trial per action video type remained in the final analysis.

In addition to this video evaluation process, we evaluated infants' gaze-samples registered by the eye-tracker to ensure they reached a minimum threshold of recorded

gaze for each trial. Regarding looking time during action videos and preferential looking during image stills (Action still, Root stills), we kept a trial if the eye-tracker recorded at least 25% of infants' gaze (e.g., Stone & Bosworth, 2019). Regarding pupil dilation after the action videos (during the 3 s presentation of the attention grabber), we kept a trial if the eye-tracker recorded at least 50% of infants' gaze to the action video (for discussion, see e.g., Hepach & Westermann, 2016; Sirois et al., 2023). Infants for whom we had enough eye-tracking data for at least two out of the three DVs—preferential looking during Action or Root Stills, or pupil dilation after action videos—were kept in the final sample. However, if the manual video evaluation process had confirmed that an infant had watched the videos, we still included their choices during the Choice Phase of the experiment. Similarly, if only the Choice Phase could not be included (e.g., no choice were made), we kept eye-tracking data from the Action Presentation Phase.

Choice Phase

Research assistants who were blind to hypotheses of the study also assessed whether (i) infants looked at the two novel roots presented during the Choice Phase of the experiment before making a choice, (ii) were looking at the novel root while they reached for it and (iii) which root type infants chose and ate. In case of a disagreement between the two independent coders, a third tie-breaker coder, who was also blind to the hypotheses of the study, evaluated the Choice Phase of the testing sessions to settle on infants' manual choices and eating behaviors. Choices were considered valid if the criteria (i) and (ii) were met.

Across all conditions, 50 infants made a valid choice, 1 infant's choice was excluded because it was not a visually-guided reach, and 14 infants did not choose.

1.3 Parent questionnaires

In order to assess whether infants' prior food experiences or eating behaviors may affect their responses, we asked parents to complete a battery of five questionnaires. All questionnaires were filled online, either before or after the lab session.

The first questionnaire assessed infant's familiarity with the different stimuli presented in the study (i.e., black carrot, parsnip and white parsley root, knife, tongs, shoehorn). In the experiment infants saw black carrot and parsnip but we also asked about white parsley root as it is similar looking to parsnip. Parents were asked: (i) whether their infant has ever seen these six objects (Yes/No) (ii) how often their infant interacts with these objects (from never to nearly every day), (ii) how often their infant sees their parent interacting with these objects (from never to nearly every day) and (iii). The stimuli were chosen to be a priori unfamiliar to infants and results from this questionnaire confirmed our assumption : Familiarity with black carrots $M = 2,74$,

familiarity with parsley roots $M = 3,58$, familiarity with parsnip $M = 5,85$; Ratings could range from 0 - Infants never saw, interacted or saw their caregivers interacting with the object - to 15 - Infants saw, interact and see their caregivers interacting with the object everyday).

The second questionnaire asked about food consumption at home and age of introduction to fruits and vegetables. Parents were asked how often their infant eats 10 typical German foods at home (i.e., milk, dairy products, bread, cereals, fresh fruits and vegetables, meat, fish, sweet products, savory snacks, ready-to-eat foods etc.). Their responses were rated on a nine-point Likert scale (0 = never to 9 = more than five times a day). Parents were also asked at what age they introduce in their infant's diet the following foods: Infant formula, pureed foods, fresh fruits and vegetables, cereal products, meat and family foods.

The third questionnaire was the Children's Eating Difficulties Questionnaire (Rigal, Chabanet, Issanchou & Monnery-Patris, 2012). This questionnaire is divided into three parts. The first part contains twelve questions and asks parents about their infant's attitude about food (e.g., My child looks forward to mealtimes). Their responses were rated on a 5-point Likert scale (1 = Very wrong to 5 = Very true). The second part contains seventeen questions and asks parents about their feeding practices (e.g., When you prepare a meal, it happens that you offer it together with another food your child likes). Their responses were rated on a 5-point Likert scale (0 = Never to 5 = Always). The last part contains twenty-one questions and asks parents about what they do when they are confronted with different feeding situations (e.g., Your child wants to eat pasta when you intended to cook vegetables. You stick to your idea of vegetables without trying to negotiate). Their responses were rated on a 4-point Likert scale (1 = Very unlikely to 4 = Very likely).

The fourth questionnaire was the Child Food Rejection Scale (Rioux, Lafraire & Picard, 2017), which directly assesses children's food neophobic and picky eating behaviors. Six questions are related to food neophobia (e.g., My child always chooses familiar food). Five questions are related to pickiness (e.g., My child refuses to eat some foods because of their texture). Parents' responses were rated on a 5-point Likert scale (1 = Strongly disagree to 5 = Strongly agree).

The last questionnaire assessed socio-demographic characteristics of the two parents as these factors can modulate children's neophobic behaviors toward foods (Cole et al., 2017). Particularly, parents were asked separately about their education. The questions were adapted from the standardized Mikrozensus survey (see e.g., Schneider, 2015). First, parents were asked if each parent has a general school-education qualification. If this was the case, they were asked about the level of school

education they had received. Next they were asked about professional education, and last about their highest qualification, with options ranging from vocational internship to PHD. Answers were then transformed into the ordered variable Years of education, ranging from 10 years (intermediate level of maturity or “Mittlere Reife”) to 21 years (PHD).

2. Supplementary Results

2.1 Infants’ responses to luminance changes

Directly after calibration, alternating light and dark stimuli were presented to assess the individual infant’s pupil dilation and constriction responses to contrast changes. In adults, pupil responses to several parameters are found to vary between individuals and groups (e.g., Lee et al., 2024; Mathôt, 2018). To our knowledge, it is not yet known if similar variation is present in infants. Such variations are very likely, since interindividual differences are generally found for the development of visual functions in infants (e.g., Kellman & Arterberry, 2007). With this, we had planned to explore the possibility to statistically control for pupil responses to luminance changes during the assessment of cognitive effects on pupil dilation on an individual basis (e.g. Bradley et al., 2017). Results showed that indeed high interindividual variability was present in the pupil reaction times of our infant participants (Schlegelmilch, 2024; further information on methods and results, as well as the underlying data is available on https://osf.io/rw35a/?view_only=7a15f61b732c4d7fba67bce275f00e71). However, because the reliability of this procedure is not yet fully understood, we decided against its inclusion in our final analysis of pupil dilation during the action presentation phase.

2.2 Comparison of proportional looking times during the action video sequence

In order to test whether infants’ attention is captured by food-relevant actions, we measured infants’ proportional looking time while the action videos were playing in alternation for a total of six trials (three repetitions of each action; see Fig 1, Panels 2 and 3 in the main text). We first compared proportional looking times during the action video sequence between the three action types (see section 3.1.1 main text).

In the model, infant participants served as a random factor to account for shared variances, as well as trials under the condition of infants. Action (Eat, Cut, Touch), Condition (“Cut vs. Touch”, “Cut vs. Eat”, “Eat vs. Touch”), Trial (1 → 6), Sex (Male, Female) and Age (continuous variable) were modeled as fixed effects. We report the ANOVA output results for the model in Table S1 below.

Proportional looking during the action videos			
Effect	χ^2	<i>df</i>	<i>p</i>
Action	11.7540	2	0.003*
Trial	19.7903	1	<.001*
Sex	0.0028	1	0.958
Age	0.5617	1	0.454

Table S1: ANOVA results for the linear mixed-effect models for infants' proportional looking times during the action video sequence. χ^2 -values for effects using. Asterisks indicate significant results.

2.3 Preferential looking during the action stills

2.3.1 Main analysis

We examined infants' preferential looking time during the Action Still part of the Action Presentation Phase (see Fig 1, Panel 4, main text) to assess whether infants' attention remained differentially captured by food-relevant actions after the dynamic action video sequences concluded.

At this point, one still frame of each of the two action videos the infant had watched were presented side by side for 30 seconds. Each still image showed the goal of each action (e.g., root in the mouth, knife cutting the root, finger touching the root; still images are shown in Figure S1). We did this to assess whether infants' attention remained differentially captured by food-relevant actions after the action video sequences concluded.

In the model, infant participants served as a random factor to account for shared variances within subjects, whereas Action (Eat, Cut, Touch), Condition ("Cut vs. Touch", "Cut vs. Eat", "Eat vs. Touch"), Sex (Male, Female) and Age (continuous factor) were modeled as fixed effects. The results revealed no significant effects of the preceding dynamic actions infants saw before looking at the still (Eat, Cut, Touch) or condition ("Cut vs. Touch", "Cut vs. Eat", "Eat vs. Touch"). Although infants exhibited

higher proportional looking times to the dynamic food-relevant action videos, infants did not exhibit longer looking times to image stills of food-relevant actions after the dynamic action sequence had concluded, compared to the touch control. Further, infants' visual attention toward a novel food was not influenced by having seen food-relevant actions being performed on it. We report the ANOVA output results for the models in Table S2 below.

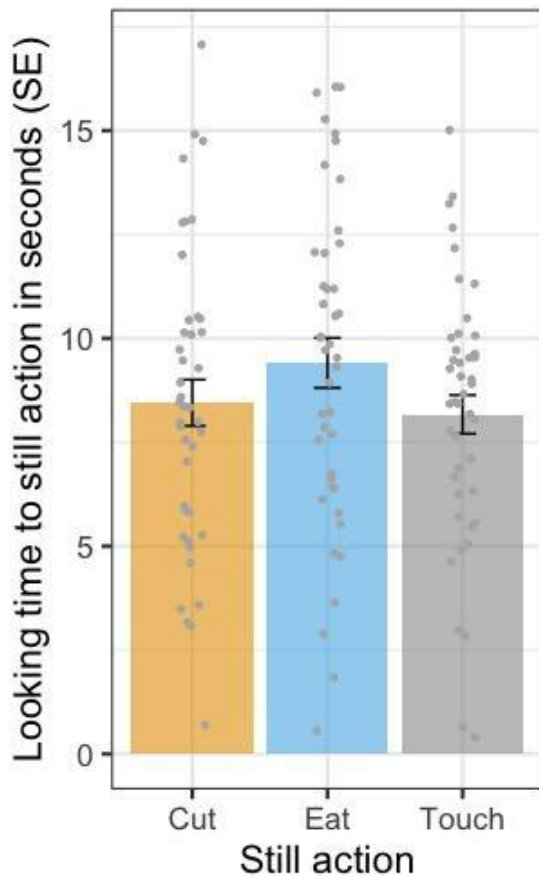


Figure S2. Infants' mean looking times to each type of action still image across the three conditions. There were no significant differences across action stills or conditions.

Preferential looking: Action Stills

Effect	χ^2	df	p
Action	3.2	2	.202
Condition	1.46	2	.482
Age	1.2	1	.294
Sex	0.2	1	.653

Table S2: ANOVA results for the linear mixed-effect models for infants' preferential looking times to the action stills

2.3.2 Exploratory analysis: Infants' gaze patterns during the action still

Although infants looked longer at the food-relevant dynamic actions, infants' attention did not remain differentially captured by food-relevant actions after the action video sequences concluded and still images of the actions were presented. A possible explanation for this finding is that infants' attention is differently captured by dynamic versus static stimuli (e.g., Courage et al., 2006). To investigate potential explanations for this result, we conducted additional follow-up analyses, examining in more detail infants's looking behaviors towards significant regions of interest (AOIs).

Specifically, we examined, for each action type (Cut, Eat, Touch) whether infants' mean looking time towards four AOIs (Action at face, Action at table, Face, Root pile) differed. Results of this follow-up analysis revealed that while viewing still images of the three actions, infants spent more time looking at the experimenter's face than at the roots being acted upon (For the cutting action, Mean looking time to the actor's face = 4.65s, SD = 2.45, Mean looking time to the action performed on the table = 3.10s, SD = 1.90, $p < 0.001$ / For the eating action, Mean looking time to the actor's face = 8.02s, SD = 3.31, Mean looking time to the root pile = 1.27s, SD = 0.93, $p < 0.001$ / For the touching action, Mean looking time to the actor's face = 4.96s, SD = 2.62, Mean looking time to the action performed on the table = 2.71s SD = 1.55, $p < 0.001$, see Fig. S3).

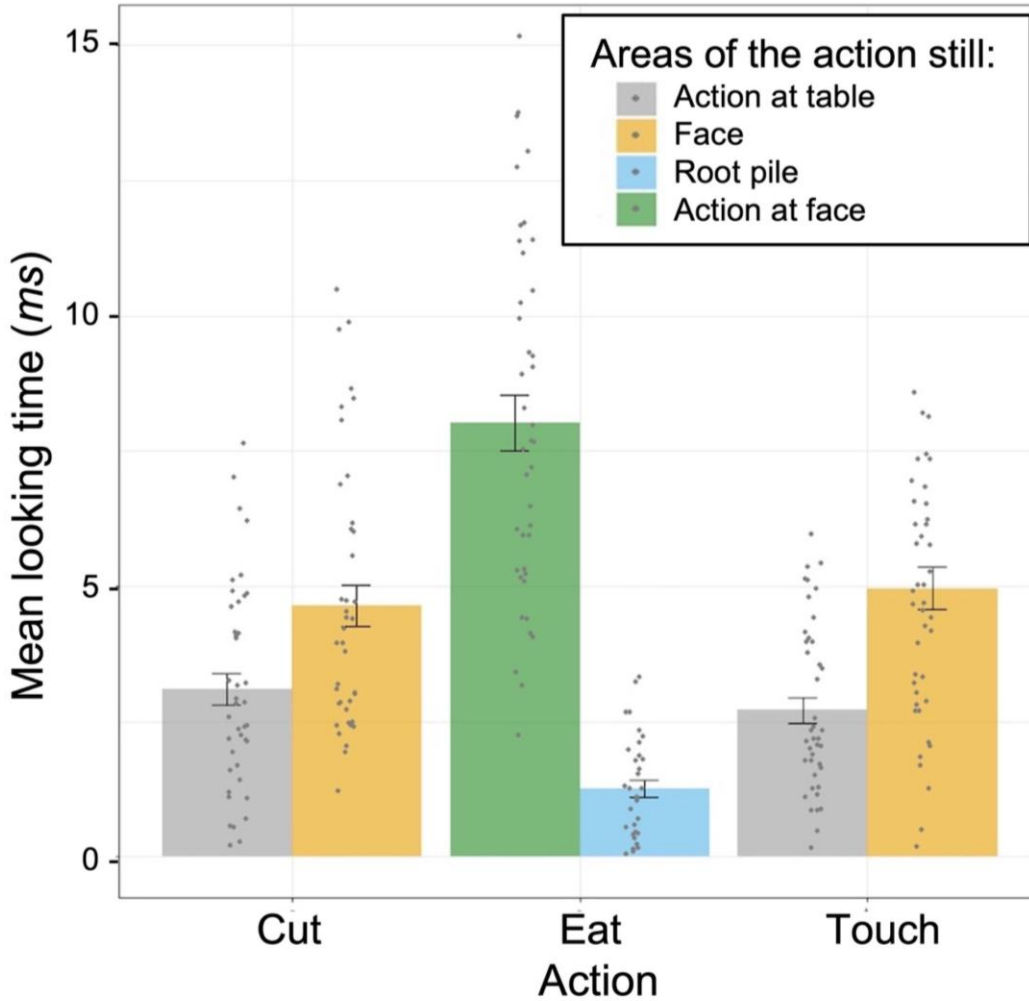


Figure S3. Mean time infants spent looking at significant areas of interest (AOI) of the action still. The AOI Action at “Face” indicates the eating action. Looking times to the actions are each averaged over the conditions in which they occur (e.g., the bar indicating looking time to the cutting action is averaged over the conditions Eat vs. Cut and Cut vs. Touch).

Next, we examined the proportion of infants’ gaze shifts between the four significant AOIs (Action at face, Action at table, Face, Root pile). Results revealed that infants’ gaze shift patterns were approximately equally divided by the regions between which they shifted their gaze: in $\frac{1}{3}$ for shifts from one side to the other side on the level of the face, $\frac{1}{3}$ for shifts from the level of the table going up to the face level—in most of the cases diagonally to the other side, and $\frac{1}{3}$ for shifts on the level of the table between the actions, or between action and root pile (see Fig. S4).

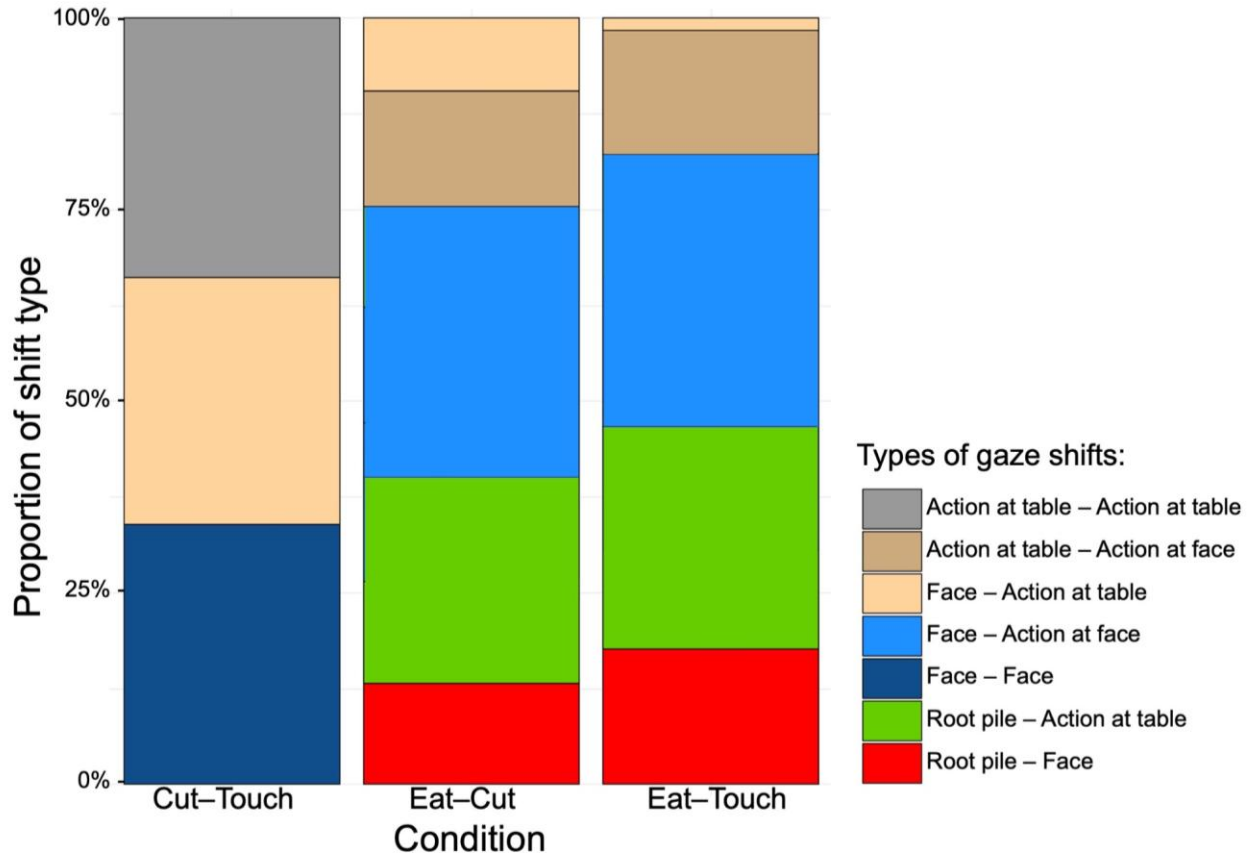


Figure S4. Proportion of infants' gaze shifts between significant areas of the action still. Areas of interest (AOI) are identical to Figure S3 above. The AOI Action at face indicates the eating action. Shift types are defined by subsequent gaze points measured at two different AOIs, independent of the order of the two AOIs (e.g., Root pile – Face can be that the infant first looked at the root pile, then at the face, or first at the face, then at the root pile, etc.). The shift types Face – Face, Action at table – Action at table, Action at table – Action at face, and Face – Action at Face are shifts between the two sides of the still, whereas the other shift types can include gaze shifts between AOIs on one side of the still, or between the two sides of the still.

2.4 Examining changes in infants' visual attention to novel foods across the two root stills

In order to test whether infants' visual attention toward the novel root stimulus was influenced by seeing food-relevant actions performed on it, we showed infants still images of both roots twice during the Action Presentation Phase. The first time they saw the root still was before any action was performed on the two roots (see Fig.1 Panel 1) and the second time they saw the root still was after infants saw the side-by-side videos of different actions performed on the two types of roots (see Fig. 1 Panel 5). Infants' gaze was recorded to determine which root type they preferred to attend to during each root still image. In order to assess whether seeing the different actions

impacted infants' attention toward the roots, we measured the change in infants' looking time for both roots across the two time points (i.e., the mean looking time during the second root still minus mean looking time during the first root still).

In the model, infant participants served as a random factor to account for shared variances within subjects, whereas Action (Eat, Cut, Touch), Condition ("Cut vs. Touch", "Cut vs. Eat", "Eat vs. Touch"), Sex (Male, Female) and Age (continuous factor) were modeled as fixed effects. The results of this model revealed no significant effects. We report the ANOVA output results for the models in Table S3 below.

Infants' visual attention toward a novel food was not influenced by seeing food-relevant actions performed on it (see Fig. S5).

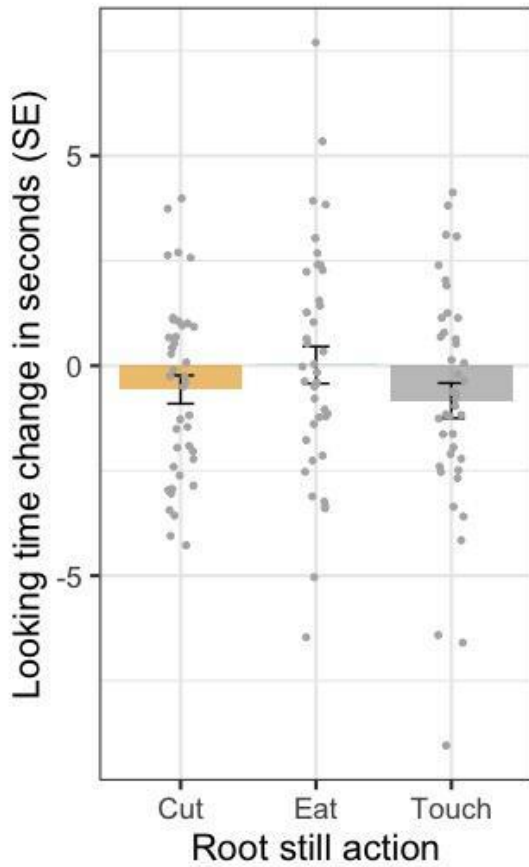


Figure S5. Differences in infants' mean looking times to the two roots across the two root stills. "Action" refers to the action performed on the root during the action video sequence. There were no significant looking time differences to the roots before and after the actions were performed.

Preferential looking: Difference Root Stills

Effect	χ^2	<i>df</i>	<i>p</i>
Action	0.27	2	0.87
Condi tion	2.90	2	0.23
Age	0.004	1	0.94
Sex	0.85	1	0.36

Table S3: ANOVA results for the linear mixed-effect models for infants' preferential looking times to the root stills.

2.5 Effect of action type and trial on infants' pupil dilation

We examined infants' pupil dilation during the action video sequence in the Action Presentation Phase (see Fig 1. Panels 2 and 3 in the main text).

Data was reduced to 60 Hz. Gaze position was assessed separately for horizontal (X) and vertical (Y) positions on the screen. Linear mixed effect models (LMM; Bates, et al., 2015) had infant participants as a random factor to account for shared variances, as well as trials under the condition of infants and side of the videos. Action (Eat, Cut, Touch), Condition ("Cut vs. Touch", "Cut vs. Eat", "Eat vs. Touch"), Trial (1 → 6), Sex (Male, Female), Age, Horizontal and Vertical gaze position and Head distance to the screen (continuous factors) were modeled as fixed effects. The dependent variable of pupil dilation was baseline-corrected by its median within individual infants and standardized.

We then conducted additional exploratory analysis by adding the interaction term Action*Trial to the model to see whether the repetitions of the different actions affected pupil dilation differently. We report the ANOVA output results for the both models in Table S4 below.

Pupil dilation with only main effects

Effect	χ^2	<i>df</i>	<i>p</i>
Action	704.8	2	<.001
Head distance	16.45	1	<.001
Trial	14.12	1	<.001
Horizontal gaze position	34.76	1	<.001
Vertical gaze position	3.89	1	.049
Sex	1.11	1	.292
Age	0.42	1	.518

Pupil dilation with Trial-Action interaction			
Effect	χ^2	<i>df</i>	<i>p</i>
Action	720.20	2	<.001
Trial	14.11	1	<.001
Head distance	12.68	1	<.001
Horizontal gaze position	28.77	1	<.001
Vertical gaze position	0.58	1	.476
Age	0.314	1	.575
Sex	0.831	1	.362
Action: Trial	627.59	2	<.001

Table S4: ANOVA results for the linear mixed-effect models for infants' pupil dilation during the action video sequence.

These results of the model with the interaction term included indicate that infants' pupil dilation changes over the trials in a way that differs across the three actions (Fig. S6). Pupil dilation showed different trajectories across the trials between all actions. For the eating action, the increase in pupil dilation by trial was highest ($b = 39$, $CI(95) = 26 - 51$, $p < .001$), while for the cutting action, the increase was less pronounced ($b = 23$, $CI(95) = 10 - 35$, $p < .001$). For the touch control action, pupil dilation did not significantly change across the trials. All comparisons between the trajectories of the Action* Trial effects differed from each other (Eat* Trial vs. Touch* Trial: $b = 32$, $CI(95) =$

30 – 35, $p < .001$; Eat*Trial vs. Cut*Trial: $b = 16$, $CI(95) = 14 - 19$, $p < .001$; Cut*Trial vs. Touch*Trial: $b = 16$, $CI(95) = 13 - 19$, $p < .001$).

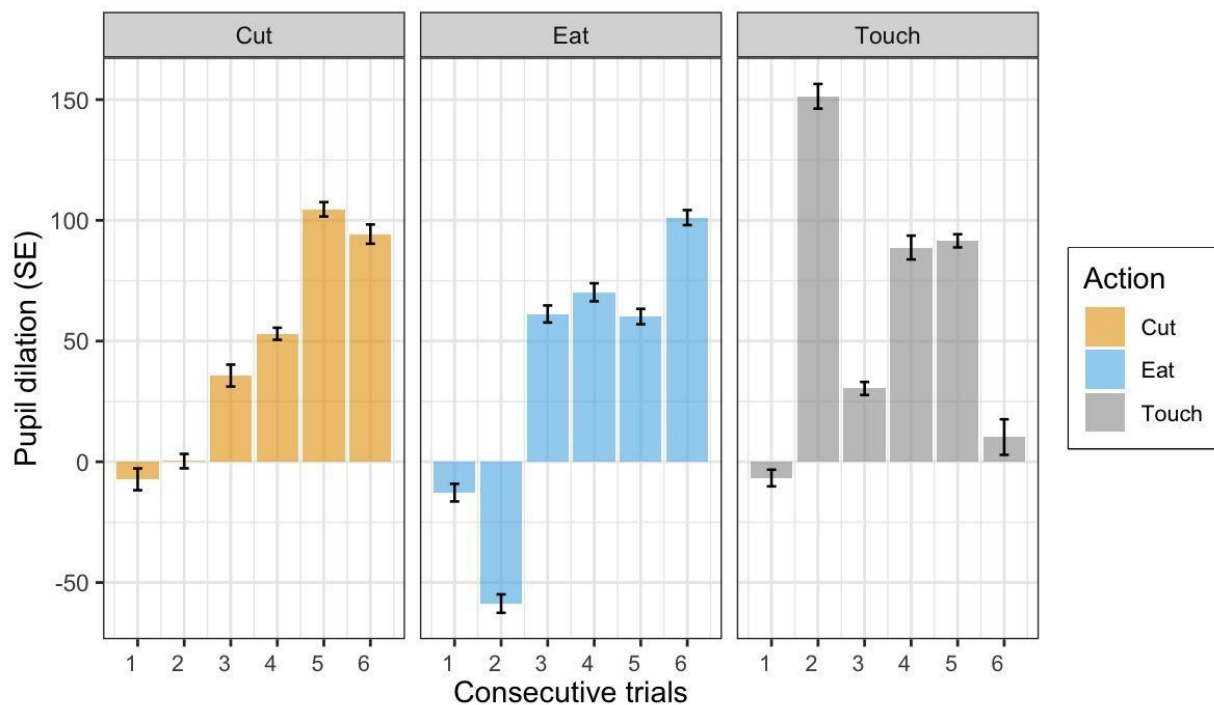


Figure S6. Infants’ pupil dilation as a function of action type and trial order. Infants’ pupil dilation increased over the trials for the food-relevant eat and cut actions, while there was no significant effect of trial for the touch control action.

The results revealed by the interaction analysis are consistent with our previous pupil dilation and looking time results suggesting that infants respond differently to the food-relevant eating and cutting actions than the touch control action. Interestingly, our looking time data suggests that infants look longer at the food relevant actions, but the pupil dilation results suggest an overall greater level of cognitive involvement after the touch control action. In contrast, with repeated presentations, cognitive effort with food relevant actions measured by pupil dilation increases, whereas looking time decreases for all actions.

2.6 Parent questionnaire correlations with DVs

In addition to our primary analysis, we assessed whether infants’ experiences and environment influenced their responses to our stimuli during the experiment. Parents had completed a battery of five questionnaires assessing their feeding practices as well as their infant's prior food experiences and eating behaviors (Questionnaire 1: Familiarity with the study stimuli; Questionnaire 2: Food consumption at home; Questionnaire 3: Infants’ eating difficulties; Questionnaire 4: Infants’ neophobic behaviors; Questionnaire 5: Socio-demographic characteristics of the family). All

correlations between the questionnaire measures and our primary DVs of interest (i.e., looking times towards dynamic actions and image stills, pupil dilation and food choices) are reported in Tables S5-S10 below.

These correlational analyses revealed that none of the questionnaire measures were systematically related to our DVs of interest. For instance, we assessed with the first and second questionnaire whether infants' familiarity with the two roots, or the age of introduction of vegetables in their diet, influenced the average times they spent looking at each dynamic action type (i.e., mean looking time per child across all consecutive trials towards cutting, eating or touching dynamic actions in relation to their prior experiences with the study objects). Interestingly, almost none of the questions assessing infants' prior experiences with the study objects were related to infants' looking times, pupil dilation or probability to make a choice. This is in line with previous findings that infants' reaching behaviors and social looking behaviors towards leafy plants and plant foods are not influenced by their' general experience with plants nor their experience with the plant foods they are presented with (Rioux & Wertz, 2021; Wertz & Wynn, 2014; Włodarczyk et al., 2018, 2020).

**Correlations between questionnaire data
and average looking times to action videos**

		Looking at eating action	Looking at cutting action	Looking at touching action
Familiarity with...	Black carrots	0.12	0.34	0.13
	White parsley roots	0.059	0.22	0.040
	Parsnips	0.070	0.29	0.040
	Knife	0.11	0.032	0.15
	Shoehorn	- 0.22	0.046	- 0.054
	Tongs	- 0.099	0.11	0.021
Age of introduction to...	Fruits	- 0.045	- 0.21	- 0.20
	Vegetables	- 0.18	- 0.11	- 0.23
Frequency of eating vegetables at home		0.087	0.22	- 0.067
Infants' Neophobia		0.10	0.29	0.10
Parental Feeding Style	Authoritarian	-0.21	0.12	0.19

INFANT FOOD CUES

	Authoritative	-0.30	-0.14	0.09
	Permissive	0.33	0.05	-0.11
	Coercion	-0.12	0.01	0.14
	Explanation	-0.10	-0.07	-0.15
Parental Feeding Practice	Contingency	0.06	0.18	0.36
	Preference	0.05	-0.09	0.04
	Caregiver 1	0.18	0.07	0.04
Education years	Caregiver 2	-0.02	0.22	0.19

Table S5. Summary of the correlations between infants' experiences and environment and average looking times towards each dynamic action type. All reported tests use Bonferroni-corrected alpha levels to account for multiple comparisons (19 questionnaire items; corrected alpha level 0.0026). No significant correlations were found.

Correlations between questionnaire data and preferential looking towards action skills

		Looking at eating still	Looking at cutting still	Looking at touching still
Familiarity with...	Black carrots	0.12	0.003	0.44* p = 0.002
	White parsley roots	0.01	-0.02	-0.02
	Parsnips	0.14	0.08	-0.02
	Knife	-0.01	-0.02	0.09
	Shoehorn	-.43	0.01	-0.29
	Tongs	-0.14	-0.17	-0.02
Age of introduction to...	Fruits	-0.21	-0.41	-0.25
	Vegetables	-0.29	-0.15	-0.09
Frequency of eating vegetables at home		-0.20	-0.18	0.02
Infants' Neophobia		0.15	0.17	0.16
Parental Feeding Style	Authoritarian	0.18	0.31	0.04

INFANT FOOD CUES

	Authoritative	-0.25	-.032	-0.21
	Permissive	-0.12	-0.12	-0.06
	Coercion	-0.14	0.09	0.19
	Explanation	-0.03	0.05	0.21
Parental Feeding Practice	Contingency	0.01	0.24	0.19
	Preference	0.006	0.16	-0.13
	Caregiver 1	0.19	0.11	0.21
Education years	Caregiver 2	0.15	0.40	0.20

Table S6. Summary of the correlations between infants' experiences and environment and preferential looking towards each action still type. All reported tests use Bonferroni-corrected alpha levels to account for multiple comparisons (19 questionnaire items; corrected alpha level 0.0026). Significant correlations are indicated with an asterisk.

**Correlations between questionnaire data
and differential looking time between root still 1 and root still 2**

		Looking at black root	Looking at white root
	Black carrots	0.08	0.06
Familiarity with...	White parsley roots	0.29	0.05
	Parsnips	0.07	-0.13

Table S7. Summary of the correlations between infants' experiences with the study foods (black carrots, white parsley roots and parsnips) and their looking time towards each food type. All reported tests use Bonferroni-corrected alpha levels to account for multiple comparisons (3 questionnaire items; corrected alpha level 0.017). No significant correlations were found.

**Correlations between questionnaire data
and differential looking between root still 1 and root still 2**

		Looking at eaten root	Looking at cut root	Looking at touched root
Familiarity with...	Black carrots	0.10	0.06	0.05
	White parsley roots	0.34	0.19	-0.008
	Parsnips	-0.006	0.09	-0.11
	Knife	0.22	-0.08	-0.32
	Shoehorn	0.04	-0.15	0.06
	Tongs	0.19	0.37	0.27
Age of introduction to...	Fruits	-0.29	0.11	0.34
	Vegetables	-0.39	0.03	0.06
Frequency of eating vegetables at home		-0.10	0.43	0.04
Infants' Neophobia		0.08	-0.12	-0.03
Parental Feeding Style	Authoritarian	0.09	0.03	0.17

INFANT FOOD CUES

Parental Feeding Practice	Authoritative	-0.26	0.34	0.16
	Permissive	-0.007	-0.14	-0.15
	Coercion	-0.10	0.08	-0.32
	Explanation	-0.29	-0.10	0.03
	Contingency	-0.13	0.01	-0.06
	Preference	-0.001	-0.27	-0.21
	Education years	Caregiver 1	-0.04	0.22
Caregiver 2		0.19	0.18	-0.15

Table S8. Summary of the correlations between infants' experiences and environment and differential looking towards the root stills. All reported tests use Bonferroni-corrected alpha levels to account for multiple comparisons (19 questionnaire items; corrected alpha level 0.0026). No significant correlations were found.

**Correlations between questionnaire data
and pupil dilation towards each dynamic action**

		Pupil dilation to eating action	Pupil dilation to cutting action	Pupil dilation to touching action
Familiarity with...	Black carrots	-0.12	0.14	-0.10
	White parsley roots	-0.10	-0.09	-0.19
	Parsnips	-0.12	0.07	-0.07
	Knife	-0.14	0.12	-0.07
	Shoehorn	0.25	-0.05	-0.06
	Tongs	-0.12	-0.01	0.14
Age of introduction to...	Fruits	0.19	0.11	-0.07
	Vegetables	0.09	0.001	-0.07
Frequency of eating vegetables at home		-0.11	0.29	0.11
Infants' Neophobia		0.19	0.24	0.02
Parental Feeding Style	Authoritarian	0.16	-0.02	0.16

INFANT FOOD CUES

Parental Feeding Practice	Authoritative	0.27	-0.004	0.06
	Permissive	-0.01	-0.05	0.10
	Coercion	0.01	0.23	-0.02
	Explanation	0.14	0.37	-0.03
	Contingency	0.35	0.40	-0.002
	Preference	0.14	-0.03	0.01
	Education years	Caregiver 1	-0.03	-0.06
	Caregiver 2	0.04	0.03	0.16

Table S9. Summary of the correlations between infants' experiences and environment and baseline-corrected pupil dilation towards each dynamic action type. All reported tests use Bonferroni-corrected alpha levels to account for multiple comparisons (19 questionnaire items; corrected alpha level 0.0026). No significant correlations were found.

**Correlations between questionnaire data and
propensity to make a choice depending on the action
that was performed on the food**

	Choice (Yes/No)
Familiarity with...	Black carrots -0.04
	White parsley roots -0.02
	Parsnips 0.05
	Knife 0.004
	Shoehorn 0.10
	Tongs 0.01
Age of introduction to...	Fruits -0.04
	Vegetables 0.05
Frequency of eating vegetables at home	0.12
Infants' Neophobia	-0.03
Parental Feeding Style	Authoritarian 0.20

	Authoritative	0.13
	Permissive	0.09
	Coercion	-0.09
	Explanation	-0.13
Parental Feeding Practice	Contingency	0.09
	Preference	-0.09

	Caregiver 1	0.06
Education years	Caregiver 2	0.16

Table S10. Summary of the correlations between infants' experiences and environment and their propensity to make a choice in the Choice part of the experiment (coded as Yes/No). All reported tests use Bonferroni-corrected alpha levels to account for multiple comparisons (19 questionnaire items; corrected alpha level 0.0026). No significant correlations were found.

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