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Abstract: The present study explores two hypotheses: a) women during early pregnancy should experience increased color discrimination ability, and b) women during early pregnancy should experience shifts in subjective preference away from images of foods that appear either unripe or spoiled. Both of these hypotheses derive from an adaptive view of pregnancy sickness that proposes the function of pregnancy sickness is to decrease the likelihood of ingestion of foods with toxins or teratogens. Changes to color discrimination could be part of a network of perceptual and physiological defenses (e.g., changes to olfaction, nausea, vomiting) that support such a function. Participants included 13 pregnant women and 18 non-pregnant women. Pregnant women scored significantly higher than non-pregnant controls on the Farnsworth-Munsell (FM) 100 Hue Test, an objective test of color discrimination, although no difference was found between groups in preferences for food images at different stages of ripeness or spoilage. These results are the first indication that changes to color discrimination may occur during early pregnancy, and is consistent with the view that pregnancy sickness may function as an adaptive defense mechanism.

Keywords: visual perception, color discrimination, pregnancy sickness, first trimester

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Introduction

Building in the feto-protective proposition of Hook (1978), Profet (1992) proposed the first comprehensive theory of pregnancy sickness as a way of accounting for and integrating some of the physiological and cognitive changes that take place primarily in early pregnancy. Moreover, this was the first theory of the idea that pregnancy sickness might function as an adaptation, specifically, as a set of defensive mechanisms designed to deter or limit the consumption of food-based toxins and teratogens that could be deleterious for the developing embryo. In this view, early pregnancy (which approximately overlaps with the first trimester) takes prominent place because this period coincides with embryonic organogenesis (approximately 2-8 weeks post conception), which is the time when the fetus

is most vulnerable to developmental disturbances caused by toxins and teratogens (Farquharson, Jauniaux and Exalto, 2005; O'Rahilly and Müller, 2000). If pregnancy sickness is designed as a defensive adaptation, then it should largely be a phenomenon of early pregnancy. Findings supporting this theory include the following: (a) of the most frequent and intense symptoms of pregnancy sickness (i.e., nausea, vomiting, aversions and dry heaving) coincide with the period of embryonic organogenesis (Moore and Persaud, 2008); (b) women with pregnancy sickness experience the greatest frequency of food aversions during first trimester (Bayley, Dye, Jones, DeBono and Hill, 2002; Crystal, Bowen and Bernstein, 1999); (c) food aversions tend to be directed toward foods with naturally occurring toxins and teratogens (e.g., alcohol, tobacco, meat, fish, coffee and fatty foods (Cnattingius, et al., 2000; Hook, 1978; Little and Hook, 1979; Pepper and Roberts, 2006; Walker, Walker, Jones and Verardi, 1985;) (d) olfactory sensitivity may increase during the period of pregnancy sickness (Dastur, 2000); (e) the greatest number of miscarriages occurs during the first trimester (Everett, 1997); and (f) an inverse relationship exists between increased symptoms of pregnancy sickness and the occurrence of birth defects (Maconochie, Doyle, Prior and Simmons, 2007).

Changes in olfactory, taste, and, as we propose in this paper, visual perception are likely the mechanisms by which cues associated with food toxicity are detected, typically at thresholds lower than before the pregnancy. Evidence of lowered olfactory thresholds during the first trimester has been documented along with shifts in taste perception (Dastur, 2000; Duffy, Bartoshuk, Striegel-Moore and Rodin, 1998; Gilbert and Wysocki, 1991; Nordin, Broman, Olofsson and Wulff, 2004). These results were not replicated by Kim et al. (2011) who only found evidence of increased subjective olfactory sensitivity using a questionnaire but not with a psychophysical test (the Korean Version of the Sniffin' Sticks-II test). One criticism of Kim et al.'s study is that stage of pregnancy was not controlled for, which is critical given the theoretical importance of early pregnancy in olfactory thresholds. Laska, Koch and Hudson (1996) also could not detect systematic olfactory sensitivity shifts in a longitudinal psychophysical study. This study measured detection threshold, intensity perception, hedonic evaluation and odor identification over the course of pregnancy, and compared it with non-pregnant women. Dastur (2000) on the other hand found a difference in detection threshold sensitivity, also using a longitudinal design and non-pregnant controls. The difference in findings between these two studies may be a consequence of methodological differences. For example, the phenyl-ethanol that Dastur used only activates the olfactory nerve whereas the n-Butanol used by Laska and colleagues activates both olfactory and trigeminal nerves (Doty, et al., 1978; Jacquot, Monnin and Brand, 2004), and thus is not a pure test of olfactory sensitivity.

We are not aware of any studies that have explored pregnancy-related changes in visual perception. However, visual changes have been observed during different stages of the menstrual cycle, possibly mediated by menstrual cycle related hormonal variations. Changes in visual information processing are indicated by electroencephalography (EEG) amplitude differences across the menstrual cycle (Nash, 2009; Tasman, Hahn and Maiste, 1999), and shorter visual transmission times during the ovulatory phase, measured by pattern reversal visual evoked potentials (Yılmaz, Erkin, Mavioğlu and Sungurtekin, 1998). Another study explored color changes using the FM 100 hue test (Giuffré, Rosa and

Fiorino, 2007). Sixteen female subjects were tested at three points during the cycle for visual acuity, contrast and color changes. The findings indicate that color discrimination is better during ovulation than at the beginning or end of the menstrual cycle. These studies open the door to naturally occurring variations in visual perception and indirectly give theoretical support to the idea that color discrimination may be altered during pregnancy.

We hypothesize that changes in color discrimination during early pregnancy are consistent with an adaptive view of pregnancy sickness. More specifically, we speculate that increased color discrimination would have been adaptive to early humans in their efforts to forage for and select nutritious foods. Even a small increase in the ability to detect unripe or spoiled foods should have conferred a survival advantage in an environment of limited and potentially dangerous foods. The goal of this present study is to learn about what kinds of visual changes, if any, occur in women during early pregnancy. More specifically, we are interested in examining whether or not there are any shifts in women's ability to discriminate between colors and whether or not there are any shifts in preferences for foods at varying levels of ripeness or freshness. Specifically, we test two hypotheses: (a) women during early pregnancy will exhibit increased color discrimination ability compared with non-pregnant women. Our prediction is that there will be a significant decrease of error scores on the FM 100 hue test for all hues, and second, (b) Women during early pregnancy will find images of unripe, overripe and spoiled foods less appetizing compared with non-pregnant women. Our prediction is that there will be a significant decrease in ratings of palatability for unripe, overripe and spoiled foods.

Materials and Methods

Participants

Thirty-one women participated in the study: 13 were pregnant ($M = 28.35$ years) and 18 were not ($M = 31.69$ years; $MD = 3.33$ years, $t(30) = 2.59$; $p < 0.05$). Pregnant women were, on average, between 9 and 10 weeks pregnant ($M = 9.38$, $SD = 3.92$). We recruited participants from Vancouver, British Columbia, over a 3-month period using multiple strategies (e.g., Google Adwords Internet advertising, health centre clinic boards, and word-of-mouth). All participants received a $15 honorarium. The recruitment process, primarily through Google Adwords, ran for a fixed period of time until our maximum online advertising budget was reached.

Inclusion and Exclusion Criteria
Confirmed First Trimester Pregnancy: Pregnancy was determined by self-reported confirmation of a urinary or blood test. The date of conception was also collected through self-report of the women. Acceptable means for the determination of the date of conception were obtained from an ultrasound test in combination with the results of an ovulation period test, or two weeks after the woman's last menstrual period (LMP), which approximates the time of ovulation. The two methods produce results that do not significantly deviate from each other (Olesen, Westergaard, Thomsen and Olsen, 2004). Women who were between 3-17 weeks post-conception and experienced at least one symptom of pregnancy sickness were included in the study.

Corrected to Normal Vision: Women who had normal or corrected to normal vision, such as women who wore glasses, contact lenses, or had undergone laser corrective surgery were permitted to participate in the study. One pregnant participant had a corneal transplant recently that made her eyes sensitive to light. She was included in the analyses because corneal transplants are not associated with color discrimination changes.

Age Restriction: Women who were between the ages of 20 and 39 were permitted to participate in the study. The reason for the age restriction is twofold. First, color-discrimination ability is best between the ages of 20 to 39 (Kinnear and Sahraie, 2002; Mantyjarvi, 2001). Furthermore, women above the age of 40 years have a higher proportion of miscarriages and malformations (Bewley, Davies and Braud, 2005; Calvert, Roscoe and Luckhaupt, 2004).

Non-pregnant Women: Women with normal menstrual cycles (23 to 35 day long cycles) could participate in the study. Normal length of menstrual cycle varies between 23 and 35 days with 28 days as the median length (Solomon, et al., 2001; Wilcox, Baird, Dunson, McChesney and Weinberg, 2001). Further requirements for participation were that women had to be in a non-lactating, non-menopausal phase of their lives. They could be in any phase of their menstrual cycle, but they must not have been taking hormonal contraceptives for at least 6 months.

Exclusion Criteria: Women taking pharmacological or non-pharmacological treatment for nausea and vomiting were excluded. Women who used contraceptives that alter hormonal levels were not permitted because such contraceptives have been associated with fluctuations in olfactory sensitivity and, therefore, may affect food aversions and cravings, and symptoms of nausea and vomiting (Doty, Snyder, Huggings and Lowry, 1981). Women taking drugs (e.g., Tamoxifen, hydroxychloroquine) that are known to affect visual perception were excluded from the study (Eisner and Incognito, 2006; Eisner, Burke and Toomey, 2004). Women with acquired or inherited medical conditions such as cataracts or color blindness (including monochromacy, dichromacy, protanopia, trianopia and anomalous trichromacy) were excluded from the study.

Design

All testing was performed under standard conditions in a darkened testing room between 10:00 a.m. and 6:00 p.m. Each testing session began with the administration of the FM 100 hue test (Farnsworth, 1957) and the Food Palatability Test (FPT). Participants completed both tests in a Judge IIS viewing booth equipped with SpectraLight-3 D50 bulbs, which produce full-spectrum natural light (X-Rite Corp., Grand Rapids, MI, U.S.A). The FM 100 test was used to measure participants' color discrimination ability. It is a widely used test to detect color processing abnormalities (Mäntyjärvi, 2002). The FM 100 hue test consists of 85 colored caps varying in hue and spanning the visible spectrum. The removable caps are distributed randomly among 4 trays. Color discrimination ability was measured by the accuracy with which participants placed the color caps in their correct

incremental order of hue. Scoring of the color caps is completed using software supplied by X-Rite (Grand Rapids, USA). Finally, images for the FPT were produced from a variety of foods purchased from a local grocery store (listed in Table 1).

Table 1. List of food images used for testing pregnant and non-pregnant participants.

|	Unripe to ripe	Ripe to overripe/Fresh to spoiled
Fruits	apple, banana, pear, tomato, papaya	apple, banana, pear, raspberry, tomato, papaya, broccoli, lettuce, mushroom
Vegetables	-	
Meats	-	steak

The foods were stored in the research lab at room temperature in low humidity. The warm temperature stimulated the decaying process. Due to low humidity, most foods shrank dramatically as their water content evaporated. The meat stimuli were produced by Quench Studios, an Australian studio company who shot a time-lapse video of a piece of raw beef decaying. The period of the time-lapse was one week.

The rationale for the choice of food stimuli was to expose women to decisions that could have been observed in our ancestral environment. While pregnant women are known to have aversions towards coffee and cigarettes (Kölble, von Mering, Zimmerman and Hummel, 2001; Ochsenbein-Kölble, von Mering, Zimmerman, and Hummel, 2007), these products are unlikely to have been encountered in an ancestral environment. Rather, it is foods in their suboptimal states that would have been most commonly encoutered and would have presented the greatest danger to the embryo.

We used a FujiPix S20 Pro digital camera on a tripod stand to take pictures of the fruit and vegetable stimuli. We placed the stimuli in the Judge IIS viewing booth to ensure full-spectrum lighting. The foods were photographed every 2 days for 20 days, at which point all foods had decayed. Exceptions to this rule were the broccoli and lettuce, which were recorded every day for 11 days because of their faster decaying rate. The photographs were not manipulated or touched-up in any way once transferred onto the computer.

The time-lapse photos produced 10 to 20 photos of each food type at different stages of ripeness. The number of photos depended on the length of the decay. We recruited eight expert raters to score each food image on how appetizing they found them on a scale of 1 to 6 (1: least appetizing, 6: most appetizing). The ratings produced a palatability graph, such as the example for banana shown in Figure 1. Each food-type had a different rate of decay, and a different rate of palatability decrease. For example, the banana decayed over a period of 2 weeks, and the palatability ratings show a pronounced increase from unripe to ripe stage, and then a slower decrease as the banana goes from ripe to overripe stage. For each food-type, we selected 6 images that represented that decay-palatability curve.

**Figure 1.** Mean expert-rater scores of banana as a function of decay stage.
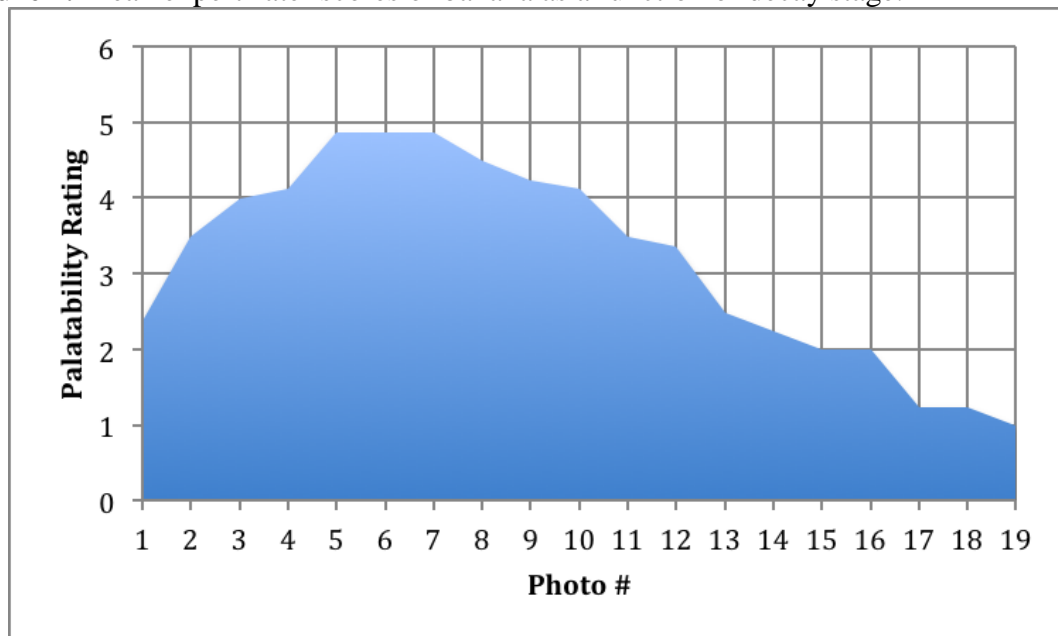
Procedure

A demographic questionnaire was used to collect general information about the participant including age, ethnic background as defined by the participant, any medical condition that might interfere with her vision, and use of glasses or contact lenses. The data were collected through an electronic form at a computer workstation and stored in a MySQL database (Oracle Corp., Redwood Shores, CA).

The FPT was administered at a computer workstation in the testing room. The food images were presented on the slide in a randomized sequence. Each slide displayed one kind of food at 6 stages of its ripeness or freshness. The unripe-to-overripe and ripe-to-overripe food sequences were analyzed separately. In order to avoid order effects, the presentation of the slides was also randomized. Each food image was rated over 3 trials. Randomization of the images ensured that the orders of the images on the slide were different across the 3 trials (see Figure 2 for an example slide).

Participants were asked to rate each photo on a Likert-like scale of 1 – 7 (anchors: 1-"very unappetizing", 4-"I would eat it", 7-"very appetizing"). The rating scale was positioned below each image. Participants were allowed to rate the foods on the screen in any order they wished. The rationale for this was that outside of a lab setting, people would be presented with a number of choices (e.g., fruits on a tree, items on a plate, vegetables in the market) from which they make a decision about the most appetizing and least appetizing foods.

Figure 2. Sample slide from the FPT. Each image was presented with a rating scale of 1-7. The sequence of images on each slide was randomized, and the presentation of slides was also randomized.
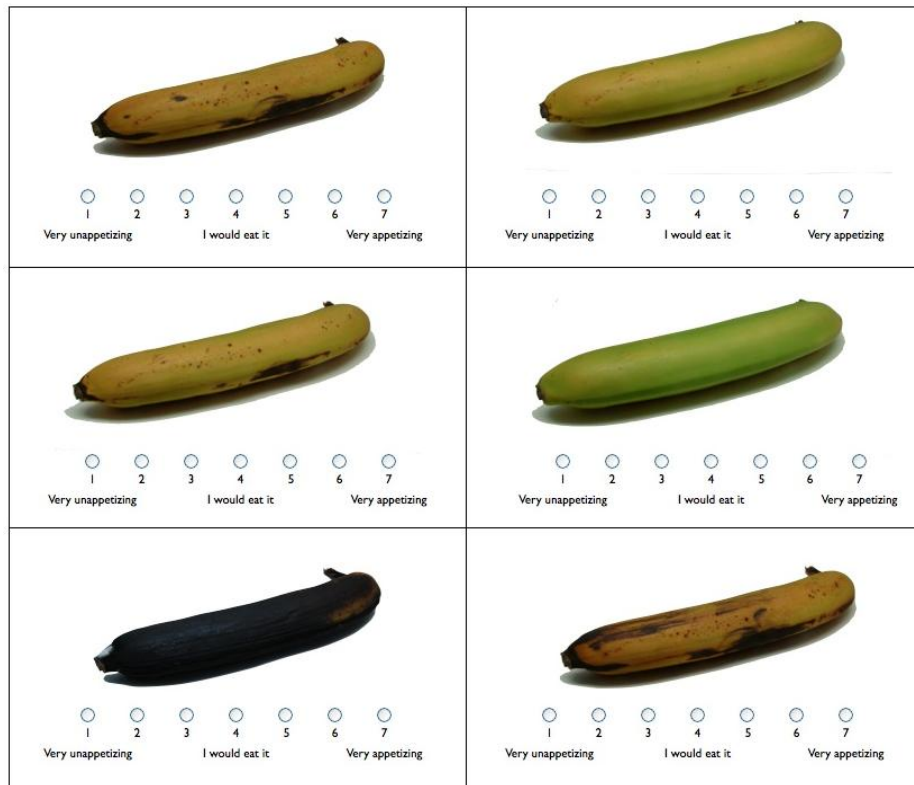

Results

FM 100 Hue Test

The FM 100 hue test score and time-to-completion were recorded. The test score was reported in terms of the log-transform of the total error scores (TES). FM100 standardization experiments recommend transforming the data because the distribution of TES for a given age group is often skewed (Kinnear, 1970; Kinnear and Sharaie, 2002; Roy, Podgor, Bronwyn and Gunkel, 1990). We performed a variation of Student's t-test that accounts for unequal sample-sizes to test the difference in the means of the log-transformed TES scores in the pregnant and non-pregnant groups. The log-transformed TES mean differences were significant with a large effect size ($MD = 0.73$, $t(30) = 2.31$; $p < .05$, Cohen's $d = .87$) (see Figure 3).

The assumptions of the unequal-samples Student's t-test have been met. The log-transform TES displays normality, and Levene's test for equality of error variances was not significant ($p > .05$). There was no difference between the two groups in the time it took participants to complete the FM 100 test ($MD = 19.7$ sec, $t(30) = 0.45$, $p > .05$, see Table 2).

Figure 3. Log-TES error scores with standard error bars between pregnant and non-pregnant women. Lower scores indicate better performance. Results significant at $p < 0.05$.
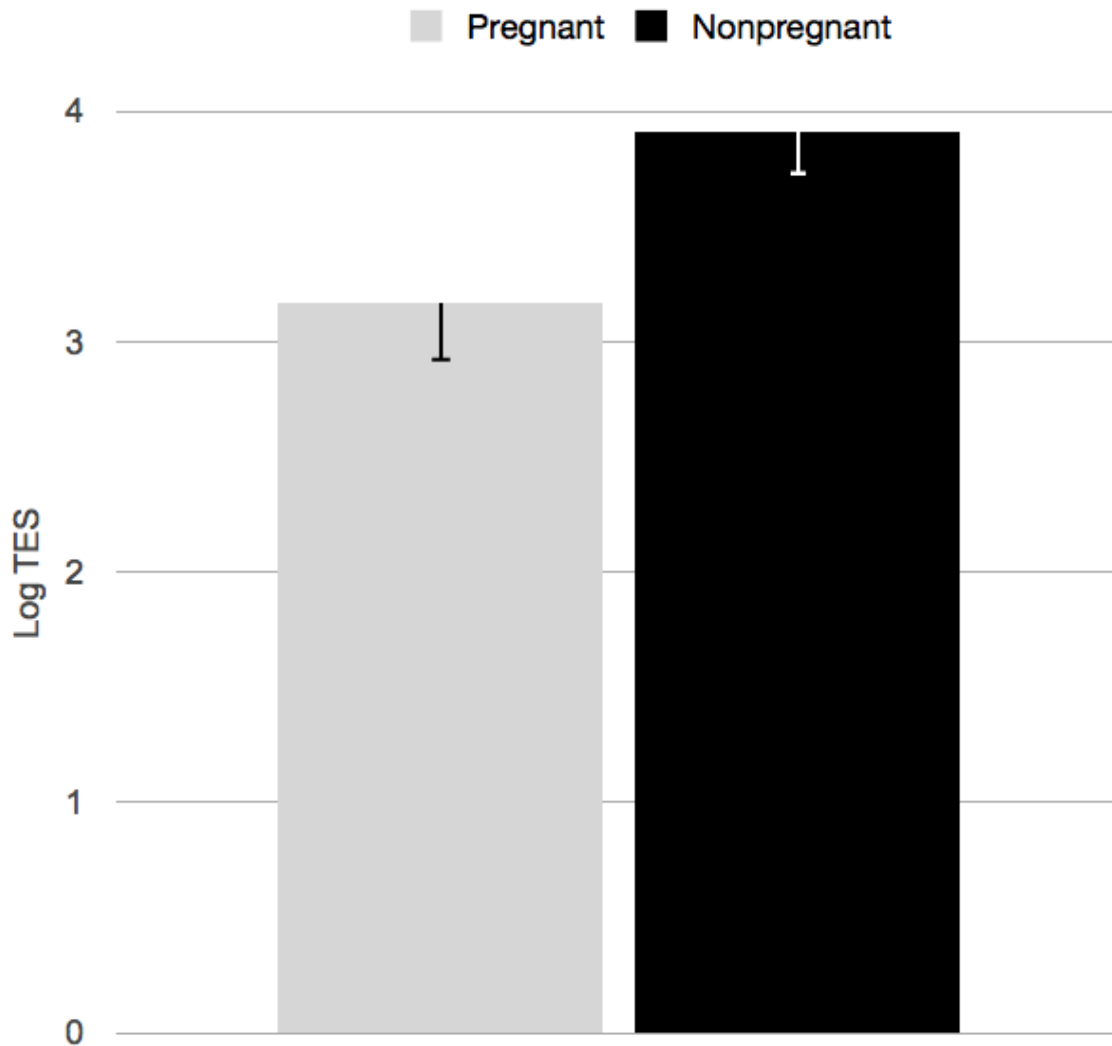
Table 2. Descriptive statistics of the Farnsworth-Munsell 100 Test. Higher log-TES scores indicate more errors on the FM 100 hue test. Higher time values indicate longer time-to-completion.

	Mean		SEM	
	Pregnant	Non-pregnant	Pregnant	Non-pregnant
Log-transform TES Score	3.17	3.91	0.26	0.19
Time	6.38	6.06	1.77	1.43

Food Palatability Test

　　For each of the six ripeness stages, we performed two mixed-design ANOVAs to determine the effect of pregnancy on the 10 different food image sets. The first analysis included all ripe-to-overripe foods as repeated measures variables, and the second analysis included foods from unripe-to-overripe state. Palatability ratings for each food image were the dependent variable in the model, and the status of the participant (pregnant or non-pregnant) was the independent variable. The means for 10 food groups are displayed in Table 3. No significant differences were found between pregnant and non-pregnant women on any of the six stages of ripeness. We do have two serendipitous findings to report.

　　Banana ratings showed significant differences on food-ripeness stages that were between ripe and overripe states. Contrary to our hypothesis that foods at extreme ends of the ripeness spectrum would show differences, three independent measures t-tests showed significant differences for the three stages in between ripe and overripe states ($t_1(26) = 2.74$, $p_1 = 0.01$, Cohen's $d_1 = 1.05$; $t_2(26) = 2.65$, $p_2 = 0.01$, Cohen's $d_2 = 1.02$; $t_3(26) = 2.44$, $p_3 < 0.05$, Cohen's $d_3 = 0.94$). While statistically non-significant, most other foods also show this trend of lower ratings for mildly overripe and unripe foods.

Table 3. Mean palatability ratings across the 10 food items.

	Stage of freshness					
Apple	Mildly Unripe					Completely overripe
Pregnant	6.14	6.08	5.65	5.46	4.99	4.57
Non-Pregnant	5.18	5.20	4.96	4.87	4.93	4.58
Banana	Mildly Unripe					Completely overripe
Pregnant	3.67	4.61	4.50	3.24	1.44	1.08
Non-Pregnant	3.00	4.67	5.16	4.02	1.80	0.93
Broccoli	Ripe					Completely overripe
Pregnant	6.80	6.20	5.10	4.00	2.20	1.10
Non-Pregnant	6.30	5.80	4.80	4.10	2.40	1.00
Lettuce	Ripe					Completely overripe
Pregnant	7.00	4.40	2.50	1.70	1.20	1.10
Non-Pregnant	6.60	4.40	2.80	2.10	1.30	1.00
Mushroom	Ripe					Completely overripe
Pregnant	4.44	1.86	1.44	1.36	1.11	1.17
Non-Pregnant	5.07	2.29	1.61	1.27	1.22	1.18
Papaya	Mildly Unripe					Completely overripe
Pregnant	5.07	4.10	2.64	1.60	1.15	1.08
Non-Pregnant	4.58	4.42	2.93	1.87	1.36	1.00
Pear	Mildly Unripe					Mildly overripe

Pregnant	5.80	5.50	4.90	4.20	2.90	1.30
Non-Pregnant	5.30	5.40	4.60	4.30	3.10	1.10
Raspberry	Ripe					Completely overripe
Pregnant	7.00	6.30	3.90	1.60	1.60	1.40
Non-Pregnant	6.60	5.60	3.60	1.70	1.70	1.20
Steak	Fresh					Decayed
Pregnant	3.50	3.40	3.30	1.90	2.22	1.10
Non-Pregnant	4.40	4.10	3.50	2.00	2.04	0.90
Tomato	Unripe					Mildly overripe
Pregnant	2.50	2.97	4.64	4.47	4.14	4.58
Non-Pregnant	2.18	2.73	4.67	5.01	4.87	4.90

We also reanalyzed the raw steak images because pregnant women made comments about how nauseating they found these images. Missing values in the pregnancy group were coded as "1" because some subjects skipped the steak images due to their nauseating quality. Having done this, the independent groups t-test for the fresh steak image is significant ($t(26) = 2.79$; $p < 0.01$; Cohen's $d = 1.07$) and the assumptions for equality of variance were met (Levene's test, $p > 0.05$).

Discussion

Results from the FM 100 hue test support our prediction that pregnant women have a significantly enhanced ability to discriminate between colors. The statistical analysis shows that women in their first trimester are better-able to discriminate between fine differences of colors. The image component of the study does not support our prediction that pregnant women find unripe and overripe foods significantly less appetizing when compared with non-pregnant women.

The result of the experiment's psychophysical component serves as another test of the hypothesis that pregnancy sickness has evolved to protect the embryo during the first trimester of pregnancy. According to our test with the FM 100, there is evidence to support visual discrimination changes during the first trimester of pregnancy. Previous research has shown that olfactory and taste sensitivity go through perceptual changes during the first trimester of pregnancy, but this is the first study to provide evidence that similar perceptual changes may be occurring in the visual domain too (Dastur, 2000; Duffy et al., 1998; Gilbert and Wysocki, 1991; Nordin et al., 2004). We think that these perceptual changes occur together because they are working in concert to filter potentially harmful foods.

These findings can be embedded in the context of Signal Detection Theory (SDT) (Green and Swets, 1966). SDT defines Type I errors as false positives, and Type II errors as false negatives or misses. Uncertainty about the kinds of toxins and pathogens a food might contain leads to a cost asymmetry favoring Type I errors (Haselton and Buss, 2000). The cost of avoiding a potentially harmful food even if it is not harmful (Type I error) is smaller than the cost of ingesting a harmful food (Type II error) (see Fig 4). In the case of

food selection during early pregnancy, the sensitivity threshold (or beta criterion) may have shifted towards a more conservative evaluation due to increased cost asymmetry between Type I and Type II errors especially during the first trimester of pregnancy. By committing a Type II error, the pregnant woman not only stands to make herself sick, but to inadvertently harm her offspring during its most sensitive period of development (organogenesis). Pregnancy sickness in the context of SDT involves a shift in the beta criterion toward decreasing the Type II error rate, which inevitably increases Type I error rates. A recent study illustrates this concept where pregnant women's aversions to odors of foods and drinks negatively affected their mood state, self-perception of illness and social interactions during early pregnancy (Swallow, Lindow, Masson and Hay, 2005). The findings are consistent with adaptive reasoning where physiological and cognitive functioning sensitivities shift to incur the least-costly error of mood-related and social-interaction issues rather than to incur the greater cost of losing the embryo.

Figure 4. The decision outcomes for pregnant women when making choices about ingesting or rejecting a food item.

	Reality	
	Toxic	**Non-Toxic**
No Toxin	Type II Error	Accurate Selection
Detect Toxin	Accurate Detection	Type I Error

(Woman's Decision)

One reason for not finding significant differences between the two groups on the subjective component of the study may be due to the increased variability introduced through individual differences. In other words, our instrument was not sensitive enough to detect differences in food palatability. The cross-sectional study design also increased the noise in the data, reducing our chances of finding a significant difference. It may be possible to overcome this obstacle by increasing the sample size, or by designing a repeated measures study where participants are tested while they are pregnant and then tested again after they give birth. Another reason for the absence of group differences on the subjective test may be due to the artificial floor created by describing the least appetizing food item as "very unappetizing". While a spoiled food looks unappetizing to most of us, pregnant women might have preferred to use a much stronger characterization to describe these foods, like "I am about to vomit". For example, everyone agrees that a rotten banana, or a

decayed raw steak look unappetizing, but some pregnant women skipped the slides due to the intensity of their reaction. The significant differences on the fresh steak image are a case in point. Some pregnant women were overcome with nausea, and opted to skip rating the image altogether. This is consistent with the embryo protection hypothesis as meats, which carry the most dangerous pathogens, are exceptionally dangerous to the embryo (Flaxman and Sherman, 2001, 2000).

Future studies could explore further changes in the visual domain by setting up the study with a longitudinal design. This allows increased experimental control and would enable the detection of more subtle changes during pregnancy. Another area that could be explored is whether or not there are any specific hues to which pregnant women become more sensitive to during the first trimester. It could be, perhaps, that first trimester women are more sensitive to yellows and reds, which are colors of ripeness. Conversely, pregnant women might become more sensitive to bluish colors that often signify fungi and rotten foods.

The present study provides support to the idea that women's visual discrimination ability may become more sensitive at least during early pregnancy, but possibly even in the latter stages of pregnancy too. This in turn provides further support that pregnancy sickness serves to protect the embryo during its most vulnerable time of development.

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