The Disentangled Sub-Processes Involved in Implied Motion Contributing to Food Freshness: The Neural Evidence from ERPs

Kaiyun Li[1,] Yan Bi[1], Yifan Wang[1], Mingxian Zhang[1], Yong-Jin Liu[2], Huijing Yang[1], and Fengxun Lin[1]

[1] School of Education and Psychology, University of Jinan, Jinan 250022, China

[2] Beijing National Research Center for Inforation Science and Technology, Department of Computer Science and Technology, Tsinghua University, Beijing 100074, China

ABSTRACT

Implied motion can enhance the consumer's judgment of food freshness. However, this enhancing effect has only been investigated for a few products. Furthermore, researchers have not conclusively determined whether the effects of the low-level visual sensory processing and high-level conceptual processing on food evaluation differ. In Experiment 1, using different fruits in static water (fruit_IS), fruit with implied moving water (fruit_IM), or only fruits as stimuli, we initially generalized the effect of implied motion on the broader category of fruit, and implied motion improved the perceived freshness of the fruit. In Experiment 2, we recorded event-related potentials (ERPs) and measured the temporal processes involved in the mechanism by which implied motion improved perceived fruit freshness. The behavioral results further supported the findings from Experiment 1. The ERP data revealed a pronounced positive difference between fruit_IM and fruit-only conditions recorded from posterior electrodes at approximately 200-300 ms (P2). This difference reflected the low-level visual implied motion sensory processing involved in the effect of implied motion on improving food freshness. Additionally, an early frontocentral negativity difference of approximately 300-500 ms between fruit_IM and fruit-only conditions was recorded, which reflected the high-level visual conceptual processing involved in the effect of implied motion on improving food freshness. These results strengthen and extend previous behavioral findings indicating that implied motion enhances the consumer's judgment of food freshness across various food categories, and improves our understanding of the cognitive processes involved in the mechanism by which implied motion influences food judgments.

KEYWORDS

implied motion
fruit freshness
taste
P2
early frontocentral negativity
low-level visual
sensory process
high-level visual
process

INTRODUCTION

Food freshness is an important attribute in judgments of food quality (Curtis & Cowee, 2009). Various food properties, such as flavor, color, odor, and texture, are conventional indicators of food freshness (e.g., Fortin, Goodwin, Thomsen, 2009; Lewis 2002). Based on empirical evidence, motion information contained in images not only conveys crucial information for our survival (Blake & Shiffrar, 2007; Rizzolatti & Sinigaglia, 2010) but also serves as a good indicator of food freshness. Depictions of food with motion (either through live viewing or video) lead to enhanced evaluations of both food freshness and appeal in multiple food domains, categories, and textures (Awad, Moharram, Shaltout, Asker, & Youssef, 2012; Mizrach, 2008). This result occurs even when motion is merely implied in a static picture (defined as implied motion), rather than being an actual feature of the stimuli (Gvili et al., 2015; Gvili, Tal, Amar, & Wansink, 2017).

Implied motion broadly refers to the dynamic information extracted from static stimuli/pictures (Kourtzi & Kanwisher, 2000). The ability to detect visual implied motion is observed very early in life;

Corresponding author: Kaiyun Li, School of Education and Psychology, University of Jinan, Jinan 250022, China. e-mail: sep_liky@ujn.edu.cn

even 5-month-old infants showed a significant visual preference for the picture with implied motion (Shirai & Imura, 2014, 2016). Research on the effect of implied motion on food evaluation is interesting because it separately measures participants' evaluations of appeal (e.g., "How appealing is the orange juice?") and freshness ("How fresh is the food shown in this picture?") while viewing a photograph that showed juice being poured into a glass (implied motion condition) and a photograph of the same juice motionless in a glass (static condition). Gvili et al. (2015) were the first to show that depictions of food with implied motion led to higher evaluations of both freshness and appeal. Furthermore, Gvili, et al. (2017) found that solid (pretzels and cereals) and liquid (orange juice) foods and more natural (water) and more artificial (yogurt) foods presented with motion in a picture were rated as fresher than foods presented as static in a picture. Consequently, since freshness plays an important role in determining the anticipated taste of food, participants evaluated the food presented with implied motion as tastier than food presented without implied motion. Generally, these behavioral findings contribute to a better understanding of how perceived implied motion leads to higher food evaluations.

However, to date, these studies are the only two behavioral-psychophysical studies that have provided an explanation of how implied motion affects food freshness and taste. As mentioned by Gvili et al. (2017), the effect of implied motion on freshness has only been studied for a few products. Further research should generalize this effect to other food categories. Moreover, as shown in the two studies by Gvili et al. (2015; 2017), the stimuli used in the implied motion condition and the static condition were not equivalent for low-level perception, as the presentation of orange juice/water/yogurt being poured into a glass (implied motion condition) had a larger physical size and higher color saturation than the presentation of orange juice/water/yogurt contained in the glass (static condition). A recently published finding revealed that people are able to quantitatively estimate the relative freshness of vegetables simply by looking at images with different color saturation levels, as a high level of color saturation makes carrots appear fresher and more attractive (Schifferstein, Wehrle, & Carbon, 2019). Additionally, the stimuli presented in each condition in the two studies only included one or two pictures, representing a limitation to further analyzing the cognitive or neural mechanism by which implied motion improves food evaluations. Therefore, in the present study, we further verified the findings that implied motion improves food evaluation by presenting rigidly controlled food stimuli, such as images with equalized size, color saturation, luminance, and contrast.

When viewing a piece of art or a picture, an individual can have appealing or pleasant experiences that are defined as an aesthetic experience. This aesthetic experience has been proven to intimately involve two processing stages in the brain. One is the low-level visual sensory processing stage, which depends on visual sensory details, such as lines, color, or motion, and is mediated by occipital regions (Oshin & Vinod, 2004). The other is the high-level conceptual processing stage, which depends on concepts or thoughts associated with viewing art or a picture to a greater extent than visual sensory details, and is mediated by prefrontal regions (Cela-Conde et al., 2004). For example, when participants viewed paintings by Van Gogh that evoked a range of implied motion experiences, functional magnetic resonance imaging (fMRI) found that the MT+ activity of the medial temporal/medial superior temporal cortex (MT/MST) correlated with the degree of implied motion experience (but not the experience of pleasantness) and activity in the right anterior prefrontal cortex correlated with the experience of pleasantness (but not the implied motion experience, Thakral, Moo, & Slotnick, 2012). As mentioned above, the behavioral tests performed by Gvili et al. (2015; 2017) confirmed that the low-level information about implied motion (which generated the experience of implied motion) in a picture of food improves food freshness, appeal, and tastiness (which is also viewed as an experience of pleasantness). Thus, researchers have speculated that the different aspects of sub-processes of food evaluation that depend on implied motion information are related to the aesthetic judgment. However, based on the results from previous behavioral experiments, researchers have not clearly determined whether the effects of low-level visual sensory processing and high-level conceptual processing on food evaluation differ. Thus, the present study further disentangled the low-level visual sensory processing and high-level conceptual processing involving in food evaluation to deepen the insight into the phenomenon of implied motion enhancing food evaluation.

One way to measure and disentangle the subprocesses of low-level visual sensory processing and high-level conceptual processing involved in the evaluation of food freshness and tastiness is to record event-related potentials (ERPs). These allow researchers to analyze the spatiotemporal dynamics of neural activity (Luck, Woodman, & Vogel, 2000), and these temporal dynamics provide sufficient insights into the sequential psychological processes involved in evaluating food. Previous studies recording ERPs have provided some support for the hypothesis that sensory information about implied motion evokes a delayed response in an area overlapping the motion-sensitive cortex, the medial temporal/medial superior temporal cortex (MT/MST) or the hMT+ complex (Fawcett, Arjan, & Singh, 2010; Li, Liu, Qu, & Fu, 2016; Lorteije et al., 2006; Proverbio, Riva, & Zani, 2009). For example, Lorteije et al. (2006) found that when participants passively viewed each still photographs of a person with (running) or without (standing) implied motion for 500 ms , two enhanced ERP components were recorded from posterior electrodes in response to photographs with implied motion after stimulus onset, with the maxima occurring at the PO4 and POz electrodes. The earlier divergence between the two conditions was a negative component from 60 to 100 ms (similar to the N1 component), which is assumed to reflect differences in the low-level stimulus between the pictures with and without implied motion, such as differences in luminosity. The later divergence was a positive component from 260 to 400 ms (similar to the P2 component), which is considered to reflect the processing of implied motion in the photograph, because the second difference was much more pronounced and the source was located in an extrastriatal source, possibly the hMT+. Furthermore, numerous neuroimaging studies performed in healthy participants have indicated a definitive role for the hMT+ (the MT/MST in humans) in processing implied motion (Kim & Blake, 2007;

Kourtzi & Kanwisher, 2000; Lu, Li, & Meng, 2016; Osaka, Matsuyoshi, Ikeda, & Osaka, 2010). Therefore, consistent with these findings, a reasonable hypothesis is that when participants view food pictures with implied motion and rate food freshness or tastiness, the N1 and particularly the P2 components, reflecting a lower level of visual sensory processing, will be substantially activated in visual motion-sensitive areas (hMT+), which is invoked by the implied motion information.

In previous electroencephalogram (EEG) studies on processes underlying aesthetic judgment, several effects on ERPs were observed that allowed researchers to determine which sub-processes were involved. Early frontocentral negativity, located at the Fz electrode at approximately 300-400 ms, has been observed for nonaesthetic judgments and interpreted as reflecting the formation of an impression (Höfel & Jacobsen, 2007). In addition, a lateralized late positivity related to the late positive component (LPC), which is more pronounced in the aesthetic judgment task, has been interpreted as reflecting evaluative categorization (Jacobsen & Höfel, 2003). Based on the aesthetic judgments analyzed to date, in the current study, we reasonably hypothesized that early frontocentral negativity or a LPC would be observed when participants evaluated food freshness, which would indicate high-level conceptual processing.

However, other components might be activated in response to high-level cognitive processing, such as the P3 component. Psychologists and neuroscientists have had a long-standing interest in the P3 component, a broad, positive, large-amplitude potential with typical peak latency from 300 to 400 ms that can be sustained to 500 ms after the presentation of stimuli, which is also called the more nebulous LPC (Polich, 2007). The P3 component reflects the response to the outcome of the stimulus evaluation and the higher-order semantic/decision-level decision making process that is specifically indexed to potentiate the response to motivationally significant events (Cohen & Polich, 1997). Furthermore, an insightful review asserted the intriguing possibility that the P300 component may originate from the neural correlate between stimulus perception and the response to that event (Verleger, 1997). The distribution of P3 on the scalp is defined as the change in amplitude over the midline electrodes (Fz, Cz, and Pz), which typically increases in magnitude from the frontal to parietal electrode sites (Johnson, 2010). Based on the fruitful P3 research, in the current study, we reasonably postulated that the P3 component would emerge at approximately 300 to 500 ms to reflect the high-level cognitive processing of the food freshness rating.

In summary, the current study had two goals. One was to examine the general effect of implied motion on improving food freshness and taste in one group of participants in Experiment 1 by controlling and enriching the food stimuli using different fruits in implied static water, implied moving water, or fruit alone conditions. The second goal was to disentangle the involvement of the low-level visual sensory processing stage and high-level conceptual processing stage in this food evaluation by recording ERPs. Based on previous ERP studies of implied motion perception, we predicted that a positive difference between the fruit that were presented with implied moving water and fruit-only conditions would be observed at approximately 200 ms over the posterior electrodes, which would reflect the low-level visual processing of implied motion information. We also measured the electroencephalography (EEG) waves of participants as they passively viewed pictures of water with implied motion (no fruit) to better understand the effect of implied motion of the evaluation of fruit, and we expected no significant difference in P2 ERP waveforms at approximately 200 ms over the posterior electrodes between the fruit with implied moving water condition and water only with implied movement condition. Regarding the high-level conceptual or decision processes involved in the fruit freshness rating, we postulated that early frontocentral negativity, a LPC, or P3 would be activated by the pictures of fruit with implied motion, water with implied motion, and fruit only. In particular, the changes in these components would be more pronounced between the fruit with implied motion condition and fruit only condition, since these involved an evaluation of the stimuli (the freshness rating).

EXPERIMENT 1

Materials and Methods

PARTICIPANTS

Thirty-seven healthy college students were paid to participate in the experiment. All participants reported normal or corrected-to-normal vision. The experiment was conducted after obtaining written informed consent from each participant and was approved by the Institutional Review Board of the School of Education and Psychology at the University of Jinan. Data from three participants were discarded because most of the rating scores were not recorded by the E-prime software. The data from the remaining thirty-four participants (19 females, M_{age} = 19.5 years, SD = 0.83, age range = 18-22 years) were used.

APPARATUS AND STIMULI

Forty-five pictures in three categories (fruit only, fruit in implied static water, and fruits with implied moving water) were collected from the Internet. In each condition, the pictures displayed fruit that are commonly encountered in daily life, such as apples, oranges, watermelon, and so forth. The pictures were normalized for mean luminance and contrast using MATLAB and the SHINE toolbox (Willenbockel et al., 2010), thus controlling the effects of color saturation and hue on the fruits' freshness ratings (Schifferstein et al., 2019). A separate group of 20 participants was first shown all 45 black/white pictures individually and made aware of the content and dynamic range of the pictures. Then, they were asked to evaluate the dynamic level of implied motion in each picture using a Likert scale (1 - completely static, 7 - mostly moving) after considering the whole range of all the pictures. Based on the ratings, 42 pictures (shown in Figure 1) that varied in three degrees of implied motion were selected as the experimental materials. Each category included 14 pictures, and a one-sample analysis of variance (ANOVA) of the degree of implied motion revealed

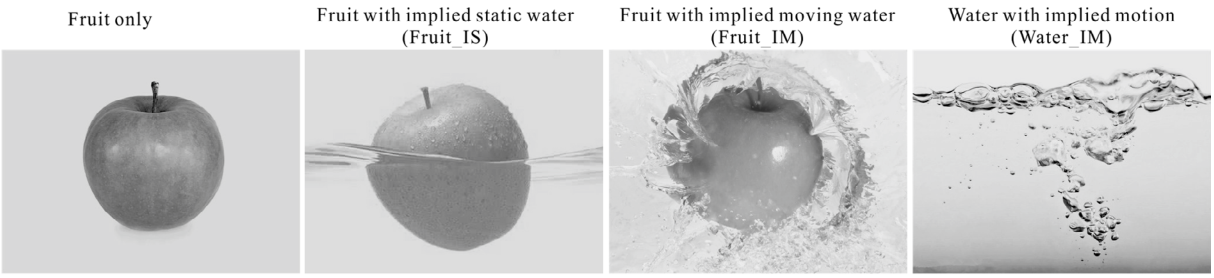

FIGURE 1.

Illustration of the stimuli used in Experiments 1 (pictures of fruit only, fruit in implied static water and fruit with implied moving water) and 2 (pictures of fruit only, fruit with implied moving water, water with implied motion).

a significant difference between these three categories ($p < .001$). The rating score for fruit in the implied moving water condition ($M = 5.75$, $SD = 1.69$) was significantly higher than the rating score for fruit in the implied static water condition ($M = 3.33$, $SD = 1.54$) and the fruit-only condition ($M = 1.46$, $SD = 0.85$). These pictures were then scaled to a fixed size of 512 × 384 pixels for the subsequent experiment.

Participants sat approximately 65 cm from an 18.5 in. cathode-ray tube (CRT) monitor (40.98 cm × 23.04 cm, 1024 × 768 pixels, 60 Hz) and were asked to keep their heads on a head-rest with their eyes focused on the center of the screen during the test session, except for rest periods (of at least 1 s) between blocks.

The experimental stimuli were presented using E-prime 2.0 software and a black-against-white background.

DESIGN AND PROCEDURE

The experimental design included three conditions: fruit-only, fruit in implied static water, and fruits with implied moving water.

For the freshness and taste rating task, each trial began with the presentation of a central fixation cross (angle of 0.8 °) for a period of 500-750 ms, which was then followed by the presentation of a picture from one the three categories at the center of the screen for 2 s. Rating numbers (1-7) then appeared at the bottom of the picture. Participants were asked to click a number using the mouse to provide a rating score for the freshness of the fruits (1 - not fresh at all; 7 - very fresh) or the taste of the fruits (1 - no taste at all; 7 - very tasty). After six practice trials, the participants completed two blocks of experimental trials (84 trials). Participants rated the fruit's freshness in the first block and taste in the second block. Pictures were randomly presented in each block.

Results

One-way ANOVAs (fruit, fruit with implied static water, and fruit with implied moving water) were conducted separately for the freshness rating and taste rating, and the Greenhouse-Geisser correction was applied to compensate for possible effects of nonsphericity on the measurements. The statistical analysis of the freshness rating yielded a significant main effect on freshness, $F(2, 66) = 141.81$, $p < .001$, $\eta_p^2 = 0.81$, in which the average freshness score for the fruit with implied moving water ($M = 5.54$, $SD = 0.11$) was significantly higher than for fruit in implied static water ($M = 5.25$, $SD = 0.13$), $p < .01$ or fruit alone, ($M = 3.71$, $SD = 0.12$), $p < .001$. The average freshness score for the fruit in implied static water was also significantly higher than for fruit alone, $p < .001$.

The statistical analysis of the tasting rating revealed a significant main effect on tasting, $F(2, 66) = 52.12$, $p < .001$, $\eta_p^2 = 0.61$, in which the average tasting score for the fruit with implied moving water ($M = 5.30$, $SD = 0.13$) was significantly higher than for fruit alone ($M = 4.03$, $SD = 0.16$), $p < .001$. The average tasting score for the fruit in implied static water ($M = 5.23$, $SD = 0.15$) was also significantly higher than for fruit alone, $p < .001$. A significant difference was not observed between the ratings for fruit in implied static water and fruits with implied moving water.

Discussion

Experiment 1 showed the positive effect of implied motion on the evaluation of fruit freshness, supporting the generalizability of the previously reported results and the hypothesis that motion (actual and implied) affects judgments of food freshness (Chang & Tuan Pham, 2013; Gvili et al., 2015; 2017; Kruger, Wirtz, Van Boven, & Altermatt, 2004; Pham & Avnet, 2009). However, the result of the fruit taste rating partially supported the hypothesis that water improved the perceived taste, regardless of its implied motion. This finding is inconsistent with the results reported by Gvili et al. (2017), who showed that when food is presented as appearing in motion, participants judge food as fresher and consequently evaluate food as tastier than when it is presented as static.

EXPERIMENT 2

In Experiment 1, participants were asked to evaluate the freshness and tastiness of fruits in pictures (fruit only or fruit with implied moving water) on a 7-point Likert scale, and the freshness rating was consistent with previous studies. However, the involvement of different temporal processing stages of food freshness ratings was not determined. Thus, in Experiment 2, which recorded ERPs, participants were asked to provide a rating on a 5-point Likert scale rather than the 7-point Likert scale to decrease the interference of the neural signal for real-time information processing which were caused by the selection of one of many detailed responses, initially confirming the freshness ratings observed in Experiment 1. At the same time, ERPs were recorded to analyze the neural activity

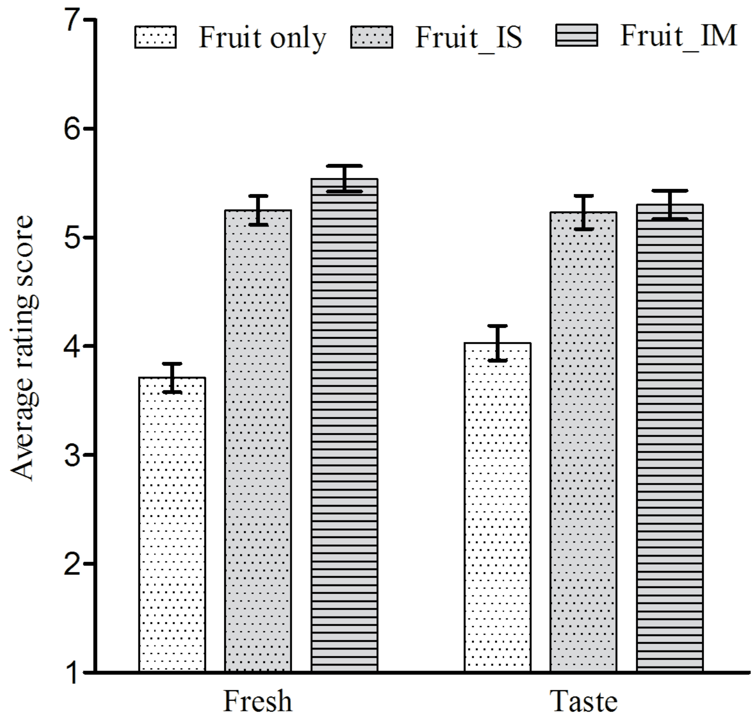

FIGURE 2.
Participants' evaluations of the freshness and taste of fruits in Experiment 1. Error bars represent 2 SEM.

of participants viewing the presented stimuli to distinguish the roles of low-level visual sensory processing and high-level conceptual processing in determining the food freshness rating..

Materials and Methods

PARTICIPANTS

Thirty healthy college students were paid to participate in the experiment. All participants reported normal or corrected-to-normal vision. The experiment was conducted after obtaining written informed consent from each participant and was approved by the Institutional Review Board of the School of Education and Psychology at the University of Jinan. Data from three participants were discarded because only 30% of total EEG segments were collected. Data for the remaining twenty-seven participants (15 females, M = 18.7 years, SD = 1.10, age range = 17-21 years) were used.

APPARATUS AND STIMULI

The stimuli used in Experiment 2 also included 28 pictures of fruit alone and fruit with implied moving water from Experiment 1; each condition included 14 pictures. We further collected 140 additional pictures from the Internet. These pictures showed fruit alone, fruit with implied moving water, and water only with implied motion. The pictures were normalized for mean luminance and contrast using MATLAB and the SHINE toolbox (Willenbockel et al., 2010). A separate group of 20 participants were first shown all 140 pictures individually and made aware of the content and dynamic range of the pictures. They were then asked to evaluate the dynamic level of implied motion in each picture using a Likert scale (1 - completely static, 7 - mostly moving) after considering the whole range of all the pictures. Based on the ratings, 90 pictures (30 pictures for each condition, including 28 pictures from Experiment 1), which varied in two degrees of implied motion, were selected for use in Experiment 2 (shown in Figure 1). A paired t-test revealed that the implied degree of motion in the water with implied motion condition (M = 6.28, SD = 0.26) and fruit in the implied moving water condition (M = 6.51, SD = 0.15) were significantly higher than the fruit alone condition (M = 1.29, SD = 0.18), $ps < .001$. These pictures were then scaled to a fixed size of 512 × 384 pixels for the subsequent experiment.

Participants sat approximately 65 cm from an 18.5 in. cathode-ray tube (CRT) monitor (40.98 cm × 23.04 cm, 1024 × 768 pixels, 60 Hz) and were asked to keep their heads on a head-rest with their eyes focused on the center of the screen during the test session, except for rest periods (of at least 1 s) between blocks. The experimental stimuli were presented using E-prime 2.0 software and a black-against-white background.

Continuous EEGs were recorded using 64 electrodes mounted in an elastic cap (Electro-Cap International, Inc.) that was connected to the left mastoid.

DESIGN AND PROCEDURE

The experimental design was relatively simple and included three conditions (fruits, fruits with implied moving water, and water with implied motion).

Each trial began with the presentation of a central fixation cross (angle of 0.8 °) for a period of 500-750 ms, which was then followed by the presentation of a picture from one of the three conditions at the center of the screen for 2 s. If the picture contained fruit, rating numbers (1-5) then appeared at the bottom of the picture, (1 - not fresh at all; 5 - very fresh). Participants were instructed to click a number using the mouse to provide a rating score for the fruit's freshness as quickly as possible within 3 s. If no fruit was depicted in the picture, participants merely focused on the picture and did not provide a rating. The next trial began after a blank screen was displayed for 1 s. Each picture was presented twice, and there were 90 trials in sum in the Experiment 2.

RECORDING OF ERP AND DATA ANALYSIS

The data were analyzed offline and then rereferenced to the average of the left and right mastoids (M1 and M2). The vertical (VEOG) and horizontal (HEOG) electro-oculograms were recorded with bipolar channels from sites above and below the midpoint of the left eye and next to the outer canthi of each eye. Mild skin abrasion was performed to reduce electrode impedance less than 5 kΩ. The EEG was bandpass filtered from 0.05 to 100 Hz, amplified with a gain of 500, and stored on a computer at a sample rate of 1000 Hz (Syn-Amps 4.5, Neuroscan, Inc.).

The continuous EEG signal was corrected for blink artifacts using an eye movement reduction algorithm (Semlitsch, Anderer, Schuster, & Presslich, 1986; Picton et al., 2000) and was segmented into individual epochs beginning 200 ms prior to the presentation of the picture and ending 2 s after the presentation of the picture. The epochs were digitally filtered (low pass = 30 Hz, high pass = 1 Hz) and baseline-corrected against the mean voltage during the 200-ms prestimulus period. The trials were automatically eliminated if the voltage in the epoch exceeded ± 100 μV. Based on previous studies (Höfel & Jacobsen, 2007; Johnson,2010; Lorteije et al. 2006) and the butterfly plot of each component obtained using for the picture-triggered epoch Neuroscan 4.5 software, we measured posterior ERP components that were identified over the posterior electrodes (P5/P6, PO5/PO6, and Pz/POz), including the P1 (100-150 ms), N2 (150-200 ms), and P2 (200-300 ms) components, frontier ERP components that were identified over the frontier electrodes (F5/F6, FC5/FC6, and Fz/FCz), including P1 (90-130 ms), N1 (130-180 ms), N2 (180-300 ms), and early frontocentral negativity or LPC or P3 components (300-500 ms). For each ERP component, a separate 2-way repeated ANOVA with picture type (fruit, fruit with implied moving water, water with implied motion) and hemisphere (left, central, right) was conducted. Voltages recorded from P5/PO5 or F5/FC5 located in the left hemisphere, Pz/POz or Fz/FCz located in the central region, and P6/PO6 or F6/FC6 located in the right hemisphere were separately averaged together.

The standardized low-resolution brain electromagnetic tomography software (sLORETA, Pascual, 2002) was used to perform the voxel-by-voxel within-group comparisons of the current density distribution of the P2 component at the posterior electrode. Specifically, the sLORETA built-in voxel-wise randomization tests (5000 permutations), which are based on statistical nonparametric mapping corrected for multiple comparisons, were performed for each cue type within groups to identify potential differences. The results correspond to maps of *t*-statistics of log-transformed data for each voxel, with a corrected $p < .05$. Anatomical labels are reported using an appropriate correction from the Montreal Neurological Institute (MNI) space to the Talairach space (Brett, Johnsrude, & Owen, 2002).

Results

BEHAVIORAL DATA

A paired *t*-test comparing the freshness ratings of the fruit alone condition and the fruits with implied moving water condition was conducted, and the Greenhouse-Geisser correction was applied to compensate for possible effects of nonsphericity on the measurements. According to the statistical analysis, the average freshness score for the fruit with implied moving water ($M = 3.66$, $SD = 0.38$) was significantly higher than for fruits alone ($M = 3.28$, $SD = 1.46$), $t(26) = -4.34$, $p < .001$.

EVENT-RELATED POTENTIAL RESULTS

The ERP components at posterior electrodes. For the P1, N1, and P2 components, a separate 2-way repeated-measures ANOVA with picture type (fruit, fruit with implied moving water, water with implied motion) and hemisphere (left, central, right) as factors was conducted (P5/P6, PO5/PO6, and Pz/POz).

P1. The analysis of the average amplitude of P1 (the time window of 100-150 ms) revealed no main effect of picture type, $F(2, 52) = 1.22$, $p > .05$. A highly significant main effect of hemisphere, $F(2, 52) = 14.64$, $p < .001$, $\eta_p^2 = 0.36$, was observed, with a higher voltage recorded from electrodes placed at the left (1.26 μV) and right hemispheres (1.42 μV) than from the central (0.03 μV) electrodes, *ps* < .05. A significant interaction between the picture type and hemisphere was observed, $F(4, 104) = 10.12$, $p < .001$, $\eta_p^2 = 0.28$. Further simple comparisons revealed a significantly higher voltage for fruit with implied moving water (2.35 μV) condition than for the fruit alone condition (1.09 μV) or the water with implied motion condition (0.83 μV) in the right hemisphere, *ps* < .05.

N1. The analysis of the average amplitude of N1 (the time window of 150-200 ms) revealed a significant main effect of picture type, $F(2, 52) = 3.50$, $p < .05$, $\eta_p^2 = 0.12$, in which the voltage for the fruit with implied moving water condition (0.48 μV) was marginally significantly higher than in the fruit alone condition (-0.18 μV), $p = .07$. The main effect of the hemisphere was not significant, $F(2, 52) = 0.54$, $p > .05$. A significant effect of the interaction between the picture type and hemisphere was observed, $F(4, 104) = 4.58$, $p < .01$, $\eta_p^2 = 0.15$. Further simple comparisons revealed a significantly higher voltage for the fruit with implied moving water condition (0.61 μV) than for the fruit alone condition (-0.29 μV) in the right hemisphere, *ps* < .05.

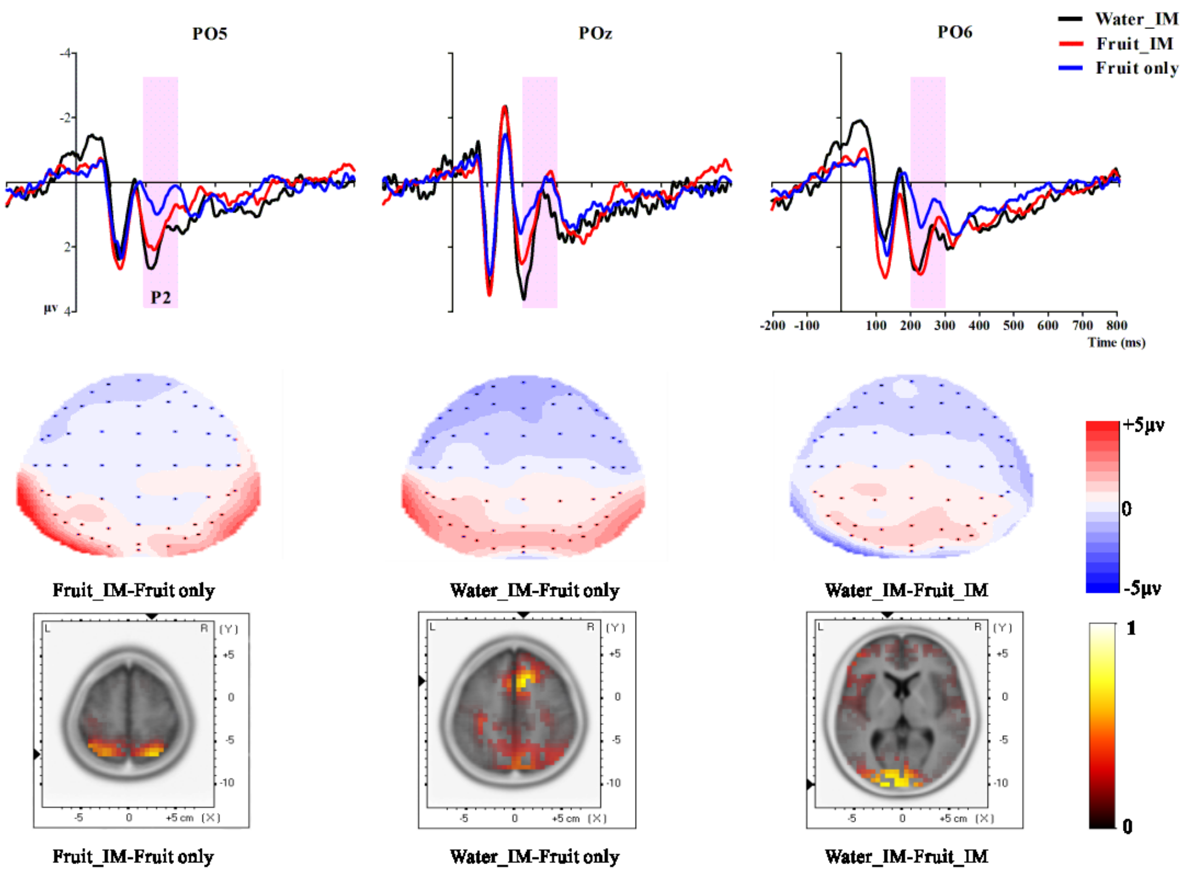

FIGURE 3.

Top panel: Average ERP waveforms elicited by cues at PO5, POz, and PO6 electrodes after cue onset. The P2 component (200-300 ms) indicated in the gray rectangles was more pronounced. Time = 0 ms indicates cue onset. Middle panel: Topographic maps of the mean voltage amplitudes for the different waveforms (the fruits with implied moving water condition minus the fruit only condition, water with implied motion condition minus the fruit only condition and water with implied motion condition minus the fruits with implied moving water (fruit _IM)) in the time window of 200-300 ms. Notice the posterior distribution of P2. Bottom panel: sLORETA source localization maps representing the current density for the comparisons of "the fruits with implied moving water condition (fruit _IM) minus the fruit only condition, water with implied motion condition (water _IM) minus fruit only condition and water with implied motion condition (water _IM) minus the fruits with implied moving water (fruit _IM)" for the P2 component. These maps represent the *t*-test results of log-transformed data computed for P2. Red to yellow colors indicates areas of stronger activation among the three conditions.

P2. The analysis of the average amplitude of P2 (the time window of 200-300 ms) revealed a significant main effect of picture type, $F(2, 52) = 21.57$, $p < .001$, $\eta_p^2 = 0.45$. Further analysis revealed a significantly higher voltage for water with implied motion condition (1.73 μV) than the fruit alone condition (0.57 μV), $p < .001$, and the voltage for fruit with implied moving water condition (1.25 μV) was also significantly higher than for the fruit alone condition (0.57 μV), $p < .01$. The main effect of hemisphere was also significant, $F(2, 52) = 8.49$, $p < .01$, $\eta_p^2 = 0.25$. A significant interaction between picture type and hemisphere was observed, $F(4, 104) = 4.98$, $p < .001$, $\eta_p^2 = 0.16$. Further simple comparisons revealed a significantly higher voltage for the water with implied motion condition than for the fruit alone condition in both the left and right hemisphere, *ps* < .01. A significantly higher voltage was observed for the fruit with implied moving water condition than for the fruit alone condition in both the left and right hemisphere, *ps* < .01. No differences were observed between the fruit with implied moving water condition and the water with implied motion condition. At the central electrodes, the voltage for the water with implied motion condition was significantly higher than for the fruit with implied moving water condition or the fruit alone condition, *ps* < .01. The topographic distributions of the grand average difference defined as "the fruit with implied moving water condition (fruit _IM) minus the fruit-only condition, water with implied motion condition (water _IM) minus fruit-only condition, and water with implied motion condition (water _IM) minus the fruits with implied moving water condition (fruit _IM)" around P2 (200 to 300 ms) further illustrated these differences (see Figure 3, middle panel). The positive increase in P2 was characterized by a more posterior scalp distribution.

To gain insight into the source of P2 waveform differences, We generated sLORETA nonparametric statistical maps to compare the current density for the grand average difference defined as "the fruit with implied moving water condition (fruit _IM) minus the fruit-only condition, water with implied motion condition (water _IM) minus fruit-only condition, and water with implied motion condition (water _IM) minus the fruits with implied moving water condition (fruit _IM)" to obtain insights into the source of the differences in the P2 waveforms. The results are presented at the bottom of Figure 3. The results correspond to maps of the *t*-test results of log-transformed data for each voxel, with a corrected $p < .05$. The *t*-value thresholds for the one-tailed test were 0.93, 0.94, and 1.02 for "the fruit with implied moving water condition (fruit _IM) minus the fruit-only condition, water with implied motion condition (water _IM) minus fruit-only condition, and water with implied motion condition (water _IM) minus the fruits with implied moving water (fruit _IM)", respectively. The sources of the differences in the P2 waveforms were mainly located in the occipital, temporal, and parietal lobes. Specifically, significantly stronger activations observed for the fruit with implied moving water condition compared with fruit alone condition were mainly located in the superior parietal lobule. The significantly stronger activations observed for the water with implied motion condition compared to the fruit alone condition were mainly located in the superior frontal gyrus and cingulate gyrus. The significantly stronger activations observed for the water with implied motion condition compared to the fruit with implied moving water condition were mainly located in the middle occipital gyrus and cuneus. For a detailed list of the regions involved, see Table A1.

The ERP components at frontal electrodes. At the frontal electrodes (F5/F6, Fz/FCz, and FC5/FC6), three components were evoked by the pictures, P1 (90-130 ms), N1 (130-180 ms), N2 (180-300 ms), as well as and early frontocentral negativity (300-500ms) components. Two-way repeated-measures ANOVA with picture type (fruit, fruit with implied moving water, water with implied motion) and hemisphere (left, central, right) as factors were conducted separately.

P1. The analysis of the average amplitude of P1 (the time window of 90-130 ms) revealed no main effects of picture type, $F(2, 52) = 0.95$, $p > .05$, and hemisphere, $F(2, 52) = 0.83$, $p > .05$. A significant interaction between the picture type and hemisphere was observed, $F(4, 104) = 1.27$, $p < .05$, $\eta_p^2 = 0.10$. Further simple comparisons revealed no significant differences in each hemisphere between these three picture type conditions.

N1. The analysis of the average amplitude of N1 (the time window of 130-180 ms) did not reveal a significant main effect of picture type, $F(2, 52) = 0.038$, $p > .05$, or an effect of the interaction between picture type and hemisphere, $F(4, 104) = 0.27$, $p > .05$. The main effect of hemisphere was significant, $F(2, 52) = 1.44$, $p < .05$, $\eta_p^2 = 0.10$, in which the voltage recorded at the central location (-1.00 μV) was significantly lower than in the left (-0.49 μV) and right (-0.58 μV) hemispheres, *p*s < .05.

N2. The analysis of the average amplitude of N2 (the time window of 180-300 ms) revealed a significant main effect of picture type, $F(2, 52) = 40.55$, $p < .001$, $\eta_p^2 = 0.61$. Further analysis showed a significantly lower voltage for the water with implied motion condition (-1.34 μV) than for the fruit alone condition (-0.16 μV), $p < .001$ and fruit with implied moving water condition (-0.71 μV), $p < .01$. The voltage recorded for the fruit with implied moving water condition (-0.71 μV) was also significantly lower than for the fruit alone condition (-0.16 μV), $p < .01$. No main effect of the hemisphere or effect of the interaction between the picture type and hemisphere was observed.

Early frontocentral negativity. The analysis of the average amplitude of early frontocentral negativity (the time window of 300-500 ms) revealed a significant main effect of picture type, $F(2, 52) = 4.88$, $p < .05$, $\eta_p^2 = 0.16$. Further analysis revealed a marginally significantly higher voltage for the fruit alone condition (-0.73 μV) than for the fruits with implied moving water condition (-1.02 μV), $p = .055$ and the water with implied motion conditions (-1.24 μV), $p = .056$. No main effect of hemisphere or interaction between picture type and hemisphere was observed.

Correlation between behavioral measures and posterior P2 and early frontocentral negativity amplitudes. We finally performed a pearson correlation analysis between behavioral and posterior P2 and early frontocentral negativity data to obtain a better understanding of the functional implications of changes in the posterior P2 and early frontocentral negativity amplitudes in response to the freshness rating. The Pearson correlation coefficient of behavioral index in the fruit with implied moving water condition and posterior P2 and early frontocentral negativity was not significant ($\rho_{P2} = -0.27$, rhoearly frontocentral negativity = -0.24). Notably, the Pearson correlation coefficient for the fruits with implied moving water condition between the posterior P2 and early frontocentral negativity exhibited a marginally significant negative correlation ($\rho = -0.375$, $p = 0.054$). The Pearson correlation coefficient of the fruit only condition between the behavioral index and posterior P2 and early frontocentral negativity was not significant ($\rho_{P2} = -0.35$, rhoearly frontocentral negativity = -0.17). In addition, the Pearson correlation coefficient of the fruit alone condition between the posterior P2 and early frontocentral negativity was not significant ($\rho = -0.35$).

Discussion

The behavioral results obtained from Experiment 2 further supported the findings from Experiment 1 that depictions of fruits with implied moving water lead to a higher evaluation of fruit's freshness. The most intriguing ERP results were changes in the P2 component at the posterior scalp and early frontocentral negativity at the frontal scalp between the fruit with implied moving water and fruit alone conditions. A positive difference was observed in P2 between the fruits that were presented with implied motion and alone at approximately 200-300 ms over the posterior electrodes, which reflected the involvement of low-level visual sensory processing in evaluating fruit. This result was consistent with previous ERP research (Li et al., 2016; Lorteije et al., 2006) and further supported the hypothesis that a positive component from 170-400 ms (defined as the P2 component) is considered to reflect the processing of implied motion in a photograph depicting implied motion. At the frontal electrodes, early frontocentral negativity was observed within the time window of 300-500 ms between the fruit with implied motion and fruit alone conditions, which was interpreted as reflecting the formation of an impression formation (Höfel &

Jacobsen, 2007), a high-level conceptual process. Generally, the results from Experiment 2 not only revealed the underlying neural mechanism by which implied motion contributes to the food freshness but also precisely determined the subprocesses involved in the improved perception of food freshness in images depicting implied motion.

GENERAL DISCUSSION

Some studies have argued that movement (or motion), a key visual factor, serves as a heuristic for a quick judgment of freshness (Chang & Tuan Pham, 2013; Kruger et al., 2004; Pham & Avnet, 2009). Even implied motion (e.g., in a static image) may be sufficient to trigger associations of enhanced freshness. However, this effect of implied motion on improving freshness perceptions has only been investigated for a few products. Furthermore, the neural basis of food freshness processing when participants view pictures of food with implied motion remains elusive, and the involvement of the low-level visual sensory processing stage and high-level conceptual processing stage in this food evaluation have not been disentangled. Therefore, by performing two experiments, we answered these two unclear questions. In both experiments, participants were asked to evaluate the freshness of fruit in pictures (fruit alone, fruit with implied moving water, fruit in static water, or water with implied motion) using a Likert scale. The behavioral results of both experiments revealed a significantly higher average freshness score for the fruit with implied moving water (implied motion information) than for fruit alone, which generally confirmed the results from previous behavioral studies showing that motion (actual motion and implied motion) affects the judgment of freshness in various food categories (Chang & Tuan Pham, 2013; Gvili et al., 2015; Gvili et al., 2017; Kruger et al., 2004; Pham & Avnet, 2009). The ERP data in Experiment 2 revealed a pronounced positive difference in components recorded from posterior electrodes at approximately 200-300 ms (defined as P2) between fruits presented with implied moving water and alone. This difference reflected the low-level visual implied motion sensory process involved in the effect of implied motion on improving food freshness. Additionally, difference in early frontocentral negativity from approximately 300-500 ms was observed between the fruit with implied moving water condition and fruit alone, which reflected the high-level visual conceptual process (freshness rating) involved in the effect of implied motion on improving food freshness. These results (see Figure A1) improve our understanding of how implied motion influences food judgments.

In the current study, we also performed behavioral tests to measure whether implied motion enhanced the perceived taste of fruit. The results from Experiment 1 indicated that water, regardless of whether it was implied as moving or static, improved the perceived taste of fruit, which was inconsistent with the findings reported by Gvili et al. (2017). We believe that in reality, freshness is connected to taste. Food motion is commonly used by consumers as a sign that food is fresher, and consequently, this impression affects the perceived taste of food (Kivela, Inbakaran, & Reece, 1999). This effect occurs because once food is harvested or killed (meaning that it is no longer moving), it undergoes deterioration and rot that further alters the expected and experienced taste (Acebrón & Dopico, 2000). Given the effect of freshness on taste (Heenan, Dufour, Hamid, Harvey, & Delahunty, 2008; Péneau, Brockhoff, Escher, & Nuessli, 2007) , Gvili, et al. (2017) found that when food (plain white yogurt) is presented with implied motion, people judge it as fresher and consequently evaluate the food as tastier than when the food is presented as static. However, the findings from our study did not support this hypothesis. In the present study, water, regardless of whether it was moving or static, significantly enhanced the perceived taste of fruit compared with fruit presented alone, whereas implied moving water also enhanced the perceived taste, but the difference did not reach statistical significance compared with fruit presented with static water. In daily life, fruits washed with water are considered clean, which might result in tastier fruit. Thus, regardless of whether water was moving or static, it increased the perceived taste of the fruit. Of course, we do not unequivocally exclude the contribution of implied motion to the perceived taste of food. Further studies should examine whether the implied movement of dirty water instead of the implied movement of clean water, as used in the current study, would similarly improve the perceived freshness and taste of food.

In Experiment 2, we measured fruit photograph-triggered ERP responses while participants performed the fruit freshness rating task and measured implied moving water photograph-triggered ERP responses while participants passively viewed these photographs to determine the contributions of low-level sensory processing and high-level conceptual processing of implied motion to ratings of freshness. We initially observed significant differences in amplitudes (N1) of earlier components at approximately 150-200 ms after picture onset between the fruit that were presented with implied moving water (implied motion) and fruit alone over the posterior electrodes. According to previous neuropsychological studies, including a study by Lorteije et al. (2006), the timing of the N1 deviation coincides with its spatial frequency and orientation (Arakawa et al., 2000), size, and eccentricity (Busch, Debener, Kranczioch, Engel, & Herrmann, 2004). Here, we also propose that the lower level differences in the stimulus, such as the considerable differences in fruit size and eccentricity among the three types of stimuli, are responsible for the differences in N1 among these three types of photographs.

Regarding the differences in the ERP waveforms among the three conditions, we noted a more pronounced late P2 (200 to 300 ms) component over posterior occipital-parietal electrodes. The amplitude of the P2 voltage increased as the degree of motion represented by the picture increased (implied moving water > fruit with implied moving water > fruit alone). As proposed by Lorteije et al. (2006), the differences in the late P2 component observed over posterior electrodes in response to fruit with implied moving water compared with fruit alone might be caused by the presence and absence of implied motion in the photographs. Importantly, in the current study, the sLORETA source localization analysis revealed that the differences in P2 observed among the three conditions appeared to arise from areas in the occipital and temporal regions, including the medial temporal (MT) cortex. This result is consistent with previous neurophysiological and imaging studies

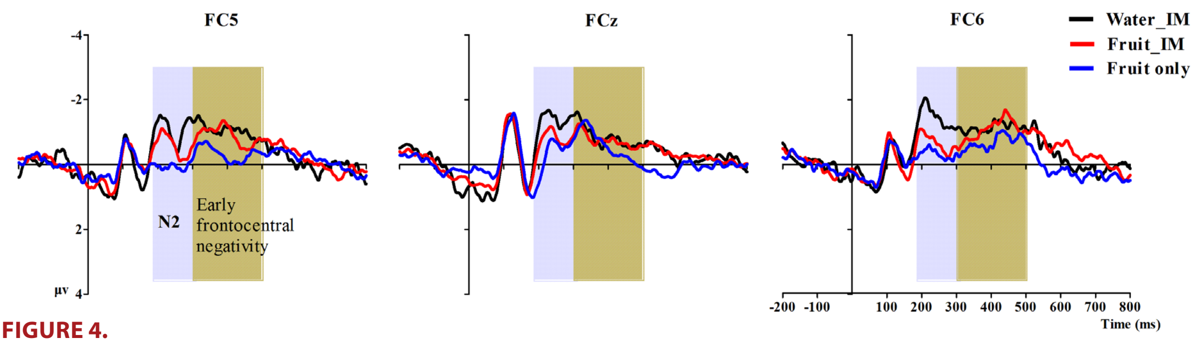

FIGURE 4.

Average ERP waveforms elicited by cues at the FC5, FCz, and FC6 electrodes after cue onset. The N2 component (180-300 ms) and early frontocentral negativity (300-500 ms) are indicated by separate gray rectangles. Time = 0 ms indicates cue onset.

showing that implied motion evokes a response in an area that overlaps with the motion-sensitive cortex (hMT+, David & Senior, 2000; Fawcett et al., 2010; Kourtzi & Kanwisher, 2000; Senior et al., 2000). The results obtained here might provide insights into the perception of implied motion derived from the temporal/occipital motion-sensitive areas, which might help enhance the perception of food freshness, and is reflected by the low-level visual sensory processes involved in the contribution of implied motion to fruit's freshness ratings.

In Experiment 2, at the frontal electrodes, the first difference in the ERP observed in response to images depicting fruit with implied motion, water with implied motion, and fruit alone was a peak in N2 during the 180-300-ms interval. Other researchers have proposed that N2 is a negative ERP that is typically evoked from 180 to 325 ms after the presentation of a specific visual or auditory stimulus and appears to be closely associated with the cognitive processes of perception and selective attention (Patel & Azzam, 2005). Several distinct N2 potentials have been characterized (Näätänen & Picton, 1986). N2a is a component with an anterior cortical distribution evoked by either conscious attention to or ignoring of a deviating stimulus (Pritchard, Shappell, & Brandt, 1991). N2b is a sharp negative component observed at a frontocentral or central electrode, often preceding P3, only during conscious attention to the stimulus. N2c arises frontally and centrally during the classification task (Patel & Azzam, 2005). As shown for the N2 component illustrated in Figure 4, the pictures of water with implied motion and fruit with implied motion triggered a larger N2a deflection than the pictures of fruit alone. According to previous findings that N2a is clearly associated with controlled processes because its occurrence depends on focal attention to that stimulus (Näätänen & Picton, 1986), a reasonable hypothesis is that implied motion information in pictures of fruit with implied moving water and water with implied motion could capture an individual's conscious attention in a controlled manner. This interpretation was confirmed by several studies of implied motion perception showing that implied motion information strongly attracts attention (Li et al., 2016; Reed, Garza, & Roberts, 2007; Shirai & Imura, 2014, 2016).

At the frontal electrodes, the most intriguing difference in the ERPs recorded in response to images depicting fruit with implied motion, water with implied motion and fruit alone was the early frontocentral negativity during the 180-300-ms interval. As mentioned in the Introduction section, early frontocentral negativity is usually observed in response to an aesthetic experience, reflecting the formation of an impression, particularly, a negative impression (Höfel & Jacobsen, 2007). In the current study, pictures of water with implied motion and fruit with implied motion triggered a larger early frontocentral negativity deflection than the pictures of fruit alone. A potential explanation for this finding is that the sensory perception of implied motion projected into a high-level conceptual impression. Notably, the Pearson correlation analysis of the fruits with implied moving water condition between the posterior P2 and early frontocentral negativity approached a marginally significant negative correlation (ρ = -0.375, p = .054), further indicating that the perception of implied motion strengthens the impression of the fruit to some extent.

However, several limitations should be noted. First, our results may be confounded because some fruits used in the current study must be peeled before they are eaten, such as bananas and pitayas, while others can be eaten without removing the peel. These mixed stimuli might weaken the moderating effect of implied motion on freshness and taste. Future investigations are warranted to verify the relationship between implied motion and taste. Second, in Experiment 2, we simply explored the neural mechanism underlying the effects of implied motion on freshness. The neural mechanism underlying the effects of implied static water on freshness must be investigated in future studies. Third, in the current study, we recorded ERPs to disentangle the involvement of low-level visual sensory processing and high-level conceptual processing in food evaluations, as this method is unable to precisely locate the areas of the brain involved in a particular response. Furthermore, some researchers have proposed that the perception of implied motion is related to the functions of both the ventral and dorsal pathways (Kourtzi, Krekelberg, & Van Wezel, 2008), which are related to the processing of visual form and motion, respectively. Electroencephalography showed that the response latency in the occipital lobe is increased by 100 ms after exposure to implied motion compared with real motion, consistent with a feedback projection following extended perceptual processing in higher level brain areas (Lorteije et al., 2006). Within the dual stream visual processing framework (Milner & Goodale, 2008), implied motion may initially activate posture-dependent neurons in the ventral visual pathway, which in turn activate motion-sensitive neurons in the dorsal visual pathway. In the current studies, we were unable to verify the function of the visual form in the effect of implied motion on the food evaluation. Future research should employ fMRI with high spatial resolution to determine the functions of visual ventral and dorsal cortical pathways and the low-level visual sensory and high-level conceptual brain areas in modulating the effect of implied motion on improving the food evaluation or quality.

In conclusion, the results from the current study provide strong empirical support for the hypothesized relationship between food motion and freshness and further extend previous behavioral findings indicating that implied motion enhances the consumer's judgment of food freshness across various food categories. More importantly, the current study is the first to examine the neural mechanism underlying this effect by recording ERPs and it contributes to a better understanding of how implied motion, in one sense, can serve as a heuristic for a quick judgment of freshness.

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APPENDIX

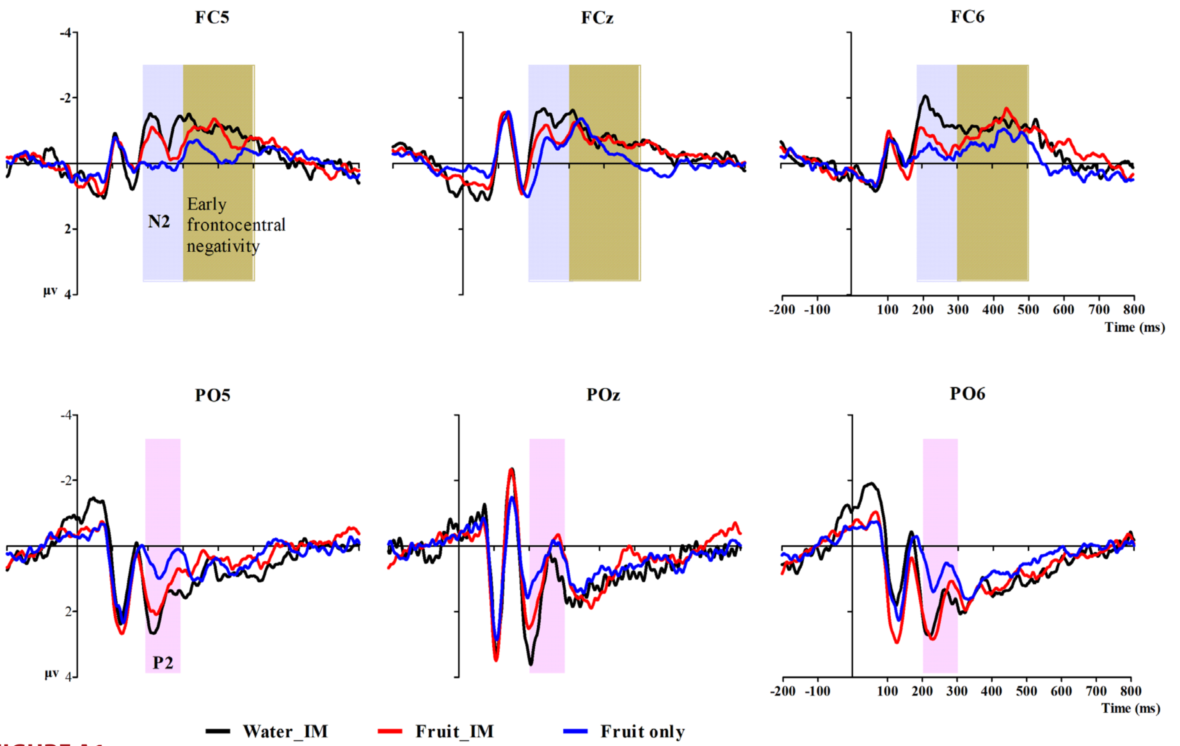

FIGURE A1.

Average ERP waveforms elicited by cues at posterior (PO5, POz, and PO6) and frontier (FC5, FCz, and FC6) electrodes after cue onset. Time = 0 ms indicates cue onset. The N2 component (180-300 ms), early frontocentral negativity (300-500 ms) and P2 compoent (200-300ms) are indicated by separate gray rectangles.

TABLE A1.

Source Localization of the P2 (200-300 ms) Differences Among the Three Conditions

Contrast	Structure	BA	L	X	Y	Z	*t*
Fruit _IM > fruit-only	Superior Parietal Lobule	7	P	25	−65	60	0.92
Water _IM > fruit-only	Cingulate Gyrus	32	Limbic	10	20	45	0.96
	Superior Frontal Gyrus	6	F	20	25	60	0.94
Water _IM > Fruit _IM	Cuneus	18	O	−15	−100	5	1.02
	Middle Occipital Gyrus	18	O	−15	−100	−10	1.02

Note. *t*-values correspond to corrected $p < .05$ (one tailed). BA = Brodmann area; L = brain lobe; O = occipital; T = temporal; P = parietal; x/y/z = Montreal Neurological institute (MNI) coordinates.