Egg Consumption Increases Vitamin E Absorption from Co-Consumed Raw Mixed Vegetables in Healthy Young Men

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Abstract

Background: Most people living in the United States underconsume vitamin E, and dietary approaches to increase the absorption of vitamin E may help individuals to meet their body's needs.

Objective: We assessed the effect of adding cooked whole egg to a raw mixed-vegetable salad on α-tocopherol and γ-tocopherol absorption.

Methods: With the use of a randomized-crossover design, 16 healthy young men (mean ± SD age: 24 ± 4 y; mean ± SD body mass index (in kg/m²): 24 ± 2) consumed the same salad (all served with 3 g canola oil) with no egg [control (CON)], with 75 g cooked egg [low egg (LE)], or with 150 g cooked egg [high egg (HE)]; a 1-wk dietary washout period was included between trials. For the first 7 d of each trial, participants consumed a low–vitamin E diet to reduce plasma vitamin E concentrations. Blood was collected hourly for 10 h and the triacylglycerol-rich lipoprotein fractions (TRLs) were isolated. α-Tocopherol and γ-tocopherol concentrations in TRLs were analyzed and composite areas under the curve (AUCs) were calculated.

Results: The α-tocopherol 0- to 10-h AUCs (AUCs0–10 h) in TRLs was higher (P < 0.05) for the HE trial (least-squares mean ± SE: 981 ± 162 nmol/L · 10 h) than for the LE (311 ± 162 nmol/L · 10 h) and CON (117 ± 162 nmol/L · 10 h) trials, which did not differ from one another. The γ-tocopherol AUCs0–10 h in TRLs was also higher (P < 0.05) for the HE trial (402 ± 54 nmol/L · 10 h) than for the CON trial (72 ± 54 nmol/L · 10 h).

Conclusion: The consumption of cooked whole eggs is an effective way to increase the absorption of α-tocopherol and γ-tocopherol from a co-consumed meal that naturally contains vitamin E, such as a raw mixed-vegetable salad, in healthy young men. This trial was registered at clinicaltrials.gov as NCT01951313.

Keywords: α-tocopherol absorption, γ-tocopherol absorption, eggs, vegetable salad, triacylglycerol-rich lipoprotein fractions

Introduction

Vitamin E is a naturally occurring, fat-soluble nutrient that contributes to the prevention of chronic diseases, including cardiovascular disease and certain types of cancer, due to its antioxidant and anti-inflammatory activities (1–3). The current RDA for vitamin E (α-tocopherol) is 15 mg/d for persons aged ≥14 y (4), but average vitamin E intakes from food and beverages by Americans aged ≥20 y are 10.3 mg/d in men and 7.7 mg/d in women (5). Nearly 90% of Americans have daily vitamin E intakes lower than their age-, sex-, and health status–specific Estimated Average Requirement (6). In addition to promoting increased vitamin E intake, dietary approaches to increase the absorption of vitamin E would help individuals meet their body's needs.

The potential health benefits of vitamin E are well known, but there is limited research on the impact of factors that affect the bioavailability of vitamin E. The absorption of vitamin E from food sources can be influenced by several factors, including the food matrix, cooking methods, amount and type of dietary lipids, and interactions with digestive enzymes or other dietary compounds (7). Because vitamin E is a fat-soluble nutrient, it is widely accepted that dietary lipid is required for the absorption of vitamin E (8, 9). Research that used an in vitro digestion model showed that α-tocopherol bioavailability was promoted by increasing the amount of soybean oil added to salad purée.
because the micellization of \( \alpha \)-tocopherol during digestion was enhanced (10). In humans, the absorption of \( \alpha \)-tocopherol was higher when participants consumed 150 mg encapsulated \( \alpha \)-tocopherol with meals containing 17.5 g dietary lipids than with meals containing 2.7 g dietary lipids (8). However, the extent to which these effects would translate to the co-consumption of a lipid-containing food in affecting the absorption of vitamin E naturally present in a complex meal is not clear.

One large whole egg (\( \sim 50 \) g) contains \( \sim 4.8 \) total lipids (11), predominantly in the yolk. We recently reported that co-consumption of 150 g (3 eggs) cooked whole eggs increased the absorption of carotenoids from a carotenoid-rich, raw, mixed-vegetable salad by 3- to 8-fold (12). Because carotenoids and vitamin E are both fat-soluble nutrients, we expected cooked whole eggs to also increase the absorption of vitamin E contained in the same salad. Therefore, the purpose of this study was to assess the effect of co-consuming cooked whole eggs with a raw mixed-vegetable salad on \( \alpha \)-tocopherol and \( \gamma \)-tocopherol absorption because \( \alpha \)-tocopherol and \( \gamma \)-tocopherol are the major forms found in Western diets (9). We hypothesized that a raw mixed-vegetable salad on \( \alpha \)-tocopherol absorption comparison would increase the absorption of vitamin E contained in the same salad.

**Methods**

**Participants**

Seventeen healthy, nonsmoking young men were recruited from the greater Lafayette, Indiana, region and 16 of the 17 participants completed this study (Figure 1). One participant withdrew due to a personal medical condition unrelated to the study. No participants reported egg allergy. The exclusion criteria were as follows: weight change >3 kg within 3 mo, regularly exercising vigorously within 3 mo, intestinal disorders including lipid malabsorption or lactose intolerance, abnormal liver function (alanine transaminase >52 U/L or aspartate transaminase >36 U/L) or kidney function [glomerular filtration rate <60 mL/min \( \times \) 1.73 m\(^2\)], fasting blood glucose >110 mg/dL, smoking, drinking >2 servings of alcoholic drinks/d, and taking lipid-lowering medications or dietary supplements that influence plasma lipid-profile samples. Participants were also counseled to maintain their usual physical activity, weight, and take no medications or dietary supplements during the study period.

**Experimental design**

For this randomized, single-blind, crossover-design experiment, 16 participants completed 3 trials that each included consuming a controlled diet for 7 d followed by a testing day (12). In addition, 1-wk dietary washout periods were scheduled between each of the trials. The within-participant testing order randomization was determined by using SAS 9.2 software (SAS Institute). The investigators were fully blinded to the participants’ test-day meals until after all testing and sample analyses were completed, but the participants and dietitians were not blinded to the meals.

**Blood sample collections and dietary control**

Seven days before each testing day, fasting blood was collected from an antecubital vein by using venipuncture and was analyzed for plasma \( \alpha \)-tocopherol and \( \gamma \)-tocopherol concentrations. For the next 7 d of each trial, participants consumed a low-vitamin-E diet to reduce plasma \( \alpha \)-tocopherol and \( \gamma \)-tocopherol (Supplemental Table 1). During the first 5 of these days, participants were counseled to consume a diet that contained less than the Estimated Average Requirement for \( \alpha \)-tocopherol (<12 mg \( \alpha \)-tocopherol/d). On days 6 and 7 of each controlled diet period, participants consumed a diet [all foods and beverages were provided and contained <60% of the Estimated Average Requirement for \( \alpha \)-tocopherol (<7 mg \( \alpha \)-tocopherol/d)]. Participants were also counseled not to take any dietary supplements during the study period.

On each of the 3 testing days, participants arrived at the Purdue clinical research center after a 10-h overnight fast and a catheter equipped with a disposable obturator was placed into an antecubital vein. After blood was drawn, participants consumed a raw mixed-vegetable salad without eggs [control (CON)], with 75 g (\( \sim 1.5 \) eggs) scrambled whole eggs [low egg (LE)], or with 150 g (\( \sim 3 \) eggs) scrambled whole eggs [high egg (HE)]. The salad contained 100 g tomatoes, 62 g shredded carrots, 70 g baby spinach, 25 g romaine lettuce, and 5 g Chinese wolfberries, and was served with 3 g canola oil. All of the vegetables and the same brand of eggs were purchased from the same local market throughout the study period. The CON, LE, and HE salads were modified to fit the participants’ dietary needs. In the CON and LE trials, participants consumed a low-vitamin-E, low-fat lunch that contained 638 kcal, 25 g protein, 22 g fat, and 0.5 mg \( \alpha \)-tocopherol consumed. All of the controlled-diet menus and test salads were developed by registered dietitians with the use of Pronutra software version 3.3 (Viocare, Inc.), and all of the foods provided to the participants were prepared by staff in the Department of Nutrition Science Metabolic Research Kitchen at Purdue University. Before the first 7-d controlled-diet period, each participant’s habitual intake of \( \alpha \)-tocopherol and \( \gamma \)-tocopherol were estimated from 3-d diet records and by using Nutrition Data System for Research software (NDSR 2012; Nutrition Coordinating Center).

**Sample collection and analyses**

**Plasma sample collection and TG-rich lipoprotein fraction isolation.** All blood samples were collected into tubes containing EDTA and centrifuged (3000 \( \times \) g, 15 min, 4°C) to obtain plasma. Aliquots of fasting-state plasma collected before and after each of the three 7-d periods of diet control were flushed with nitrogen gas and stored at \( -80^\circ \)C until thawed for analyses. On each of the 3 testing days, fresh plasma samples were obtained from hourly blood draws and TG-rich lipoprotein fractions (TRLs) were isolated as previously reported (12). To minimize photo-oxidative reactions, all plasma pipetting and TRL isolations were carried out under red light in a dark room.

**TG and total cholesterol analyses.** Concentrations of TGs and total cholesterol in the TRLs were analyzed by using a Cobas MIRAS Plus chemistry analyzer (Roche Analytical Instruments).
α-Tocopherol and γ-tocopherol extraction and analyses. α-Tocopherol and γ-tocopherol were extracted from plasma, TRLs, and homogenates of test salad and scrambled whole eggs, along with carotenoids, as described by Kim et al. (12). All extractions were performed under red light in a dark room to minimize photo-oxidative reactions. Extracted α-tocopherol and γ-tocopherol from plasma, TRLs, test salad, and scrambled whole eggs were then analyzed by HPLC, as previously reported (12). These analysis methodologies are documented to simultaneously analyze both carotenoids and vitamin E (14). Analyzed samples were quantified by using external standard curves for α-tocopherol and γ-tocopherol (Sigma-Aldrich).

Power calculation and statistical analysis
Power calculations were not performed specifically for the vitamin E outcomes currently reported. The sample size of n = 16 participants for this randomized crossover study was based on a power calculation from previous research, which showed that the total carotenoid concentration 0- to 10-h AUC (AUC0–10 h) in TRLs was higher when the same raw mixed-vegetable salad used for the current study was consumed with 20 compared with 3 g dietary lipids (15). We estimated that a group size of ≥15 participants would provide ≥90% power at an α = 0.05 to detect a difference in carotenoid absorption when the salad was consumed with 150 g scrambled whole eggs compared with when it was consumed without eggs (i.e., with 18 compared with 3 g dietary lipids, respectively) (12). This power calculation seems reasonable to apply to the vitamin E outcomes because both carotenoids and vitamin E are absorbed along with dietary lipids.

To determine the postprandial responses of TGs, total cholesterol, α-tocopherol, and γ-tocopherol in TRLs, the concentration of each variable at each postprandial time point was baseline-corrected by subtracting its fasting concentration. Baseline-corrected α-tocopherol and γ-tocopherol concentrations in TRLs were also normalized by the α-tocopherol and γ-tocopherol contents in the test salad and scrambled whole eggs consumed each testing day. Repeated-measures ANOVA was used to determine the main effects of time (of sample collection) and trial and the time-by-trial interaction. One-factor ANOVA with post hoc Tukey’s test was also applied to examine differences between baseline-corrected α-tocopherol and γ-tocopherol concentrations at each time point and baseline-corrected positive incremental AUC0–10 h of TGs, total cholesterol, α-tocopherol, and γ-tocopherol in TRLs. Paired t tests were used to compare plasma α-tocopherol and γ-tocopherol concentrations before and after the 7-d, controlled, low-vitamin-E diet periods. For each of the 3 trials, potential differences between α-tocopherol and γ-tocopherol absorption were assessed using paired t tests. All of the analyses were performed in SAS 9.2 (SAS Institute) and unequal variances were adjusted. Data are presented as least-squares means (lsmeans) ± SEs of the lsmean (SE) unless otherwise noted, and significance was accepted at P < 0.05 (2-tailed).

Additional testing poststudy
After completing all of the experimental trials, sample analyses, data processing, and statistical analyses described above, we deemed it important to conduct an additional trial to assess the effects of consuming scrambled whole eggs alone (i.e., without co-consuming the raw mixed-vegetable salad) on α-tocopherol and γ-tocopherol absorption. The results from this additional trial are useful to evaluate the impact of co-consuming eggs with the salad on vitamin E absorption because scrambled whole eggs also contain α-tocopherol and γ-tocopherol. Therefore, we re-recruited 9 of the 16 participants who completed the initial study (12); all re-recruited participants met our inclusion criteria. After signing a new institutional review board (IRB)–approved study consent form, each participant consumed the controlled diet for 7 d, and a testing day with the same experimental protocol described above was completed. The “meal” consumed at the start of the 10-h testing period was 150 g scrambled whole eggs (no salad). The data from the HE, CON, and scrambled egg-only trials were statistically assessed by using repeated-measures ANOVA. This statistical assessment was conducted recognizing that, although the data were obtained by using a repeated-measures experimental design, this assessment included fewer participants and partial randomization of trial order. The α-tocopherol and γ-tocopherol absorption results from the HE, CON, and scrambled whole egg-only trials were also used to document the predicted compared with actual absorption of these vitamin E compounds.

Results
Participant characteristics and compliance to the 7-d, controlled, low-vitamin-E diet period. Mean ± SD age and BMI (in kg/m²) of the 16 men (8 Asian, 7 white, and 1 African American) were 24 ± 4 y and 24 ± 2, respectively (Table 1). The participants were apparently healthy with clinically normal fasting plasma glucose and lipid-lipoprotein concentrations and liver and kidney functions. The usual α-tocopherol and γ-tocopherol dietary intakes were 13.2 ± 6.8 and 16.1 ± 6.4 mg/d, respectively.

Mean plasma α-tocopherol and γ-tocopherol concentrations before the controlled low-vitamin-E diet was consumed for 7 d were 22.8 ± 2.8 and 3.2 ± 1.2 μmol/L, respectively, and 18.5 ± 2.8 and 2.3 ± 0.3 μmol/L, respectively, after the low-vitamin-E diet was consumed. The 19% and 28% (P < 0.0001) reductions in plasma α-tocopherol and γ-tocopherol concentrations are consistent with the participants successfully completing the 7-d, controlled, low-vitamin-E diet periods. Comparable participant characteristics and dietary compliance results were obtained for the subset of 9 participants who also completed the scrambled whole egg trial (Supplemental Table 2).

α-Tocopherol and γ-tocopherol contents in the test salad and scrambled whole eggs. The contents of α-tocopherol and γ-tocopherol in the test salad were 2.1 and 2.0 mg/serving, respectively (Supplemental Figure 1A, B). The contents of α-tocopherol and γ-tocopherol in the scrambled whole egg (including measurements taken during the scrambled whole egg–only trials completed after the randomized HE, LE, and CON trials) were 7.6 and 7.4 μg/g of scrambled whole egg, respectively (Supplemental Figure 1C, D). Therefore, co-consuming 75 and 150 g scrambled whole eggs provided an additional 0.57 and 1.14 mg α-tocopherol and an additional 0.56 and 1.11 mg γ-tocopherol to the test salad.

Table 1 General characteristics of young adult male participants

<table>
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<tr>
<th>Value</th>
<th>Age, y</th>
<th>24 ± 4</th>
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<tbody>
<tr>
<td></td>
<td>BMI, kg/m²</td>
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<tr>
<td></td>
<td>Blood glucose, mg/dL</td>
<td>92 ± 9</td>
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<tr>
<td></td>
<td>Plasma lipids, mg/dL</td>
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<tr>
<td></td>
<td>TGs</td>
<td>99 ± 58</td>
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<tr>
<td></td>
<td>Total cholesterol</td>
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<tr>
<td></td>
<td>HDL cholesterol</td>
<td>52 ± 12</td>
</tr>
<tr>
<td></td>
<td>LDL cholesterol</td>
<td>100 ± 28</td>
</tr>
<tr>
<td></td>
<td>Usual tocopherol intakes, mg/d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>α-Tocopherol</td>
<td>13.2 ± 6.8</td>
</tr>
<tr>
<td></td>
<td>γ-Tocopherol</td>
<td>16.1 ± 6.4</td>
</tr>
<tr>
<td></td>
<td>Plasma tocopherol, μmol/L</td>
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<td></td>
<td>Pre-7-d controlled low-vitamin-E diet</td>
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<tr>
<td></td>
<td>α-Tocopherol</td>
<td>22.8 ± 2.8</td>
</tr>
<tr>
<td></td>
<td>γ-Tocopherol</td>
<td>3.2 ± 1.2</td>
</tr>
<tr>
<td></td>
<td>Post-7-d controlled low-vitamin-E diet</td>
<td></td>
</tr>
<tr>
<td></td>
<td>α-Tocopherol</td>
<td>18.5 ± 2.6</td>
</tr>
<tr>
<td></td>
<td>γ-Tocopherol</td>
<td>2.3 ± 0.8</td>
</tr>
</tbody>
</table>

1 Values are means ± SD, n = 16.
TG and total cholesterol concentrations in the TRLs. The composite TG AUC$_{0-10}$ h in the TRLs was higher for the HE trial than for the LE and CON trials, whereas the composite total cholesterol AUC$_{0-10}$ h in the TRLs were not different among these three trials (Table 2). The consumption of 3 scrambled whole eggs alone (n = 9 participants) did not apparently influence TG or total cholesterol AUC$_{0-10}$ h in the TRLs compared with consuming them with salad (HE trial) (Table 2).

α-Tocopherol and γ-tocopherol concentrations in the TRLs. α-Tocopherol AUC$_{0-10}$h in TRLs was higher (P < 0.05) for the HE trial (981 ± 162 nmol/mL · 10 h) than for the LE (311 ± 162 nmol/mL · 10 h) and CON (117 ± 162 nmol/mL · 10 h) trials, which did not differ from one another. From hours 2 to 6, the HE trial resulted in significantly higher α-tocopherol concentrations in TRLs than the LE and CON trials (Figure 2A). The γ-tocopherol AUC$_{0-10}$ h in TRLs was also higher (P < 0.05) for the HE trial (402 ± 54 nmol/mL · 10 h) than for the CON trial (72 ± 54 nmol/mL · 10 h), but no difference was observed between the HE and LE trials (226 ± 54 nmol/mL · 10 h). From hours 3 to 6, the HE trial resulted in significantly higher γ-tocopherol concentrations in TRLs than the CON trial (Figure 2B).

Comparison between α-tocopherol and γ-tocopherol absorption. Expressed per milligram of intake, α-tocopherol and γ-tocopherol absorptions were not different between the CON and LE trials, but the absorption of α-tocopherol was higher than γ-tocopherol for the HE trial (303 ± 83 compared with 129 ± 94 nmol/mL · 10 h; P < 0.05) (Table 3).

Predicted compared with actual vitamin E absorption. Among the 9 participants who also completed the scrambled whole egg–only trial, mean ± SE α-tocopherol AUC$_{0-10}$h in TRLs when the salad (CON) and 3 eggs were consumed separately were 76 ± 23 and 305 ± 80 nmol/mL · 10 h, respectively. If the consumption of these foods together would not influence the absorption of α-tocopherol contained in each food separately then the predicted total absorption would be 381 nmol/mL · 10 h (76 + 305). However, the co-consumption of salad and 3 eggs (HE trial) resulted in an actual α-tocopherol absorption of 992 ± 397 nmol/mL · 10 h. Thus, actual α-tocopherol absorption in the HE trial was 1.6-fold higher than the predicted absorption. By presuming that the absorption of the α-tocopherol contained in eggs was not changed by co-consumption of the salad (157 nmol/mL · 10 h), then co-consumption of 3 eggs increased the absorption of γ-tocopherol contained in the salad by 2.2-fold compared with when the salad was consumed without eggs. Expressed per milligram of intake, γ-tocopherol absorptions were as follows—salad (CON): 30 ± 15 nmol/mL · 10 h; 3 eggs only: 142 ± 30 nmol/mL · 10 h; predicted (salad + eggs): 70 nmol/mL · 10 h; and actual (HE): 112 ± 32 nmol/mL · 10 h per milligram of γ-tocopherol intake (Supplemental Figure 2B). The γ-tocopherol AUC$_{0-10}$ h in TRLs (Ismean ± SE) was higher for actual than for scrambled whole egg–only trial and CON (348 ± 50 compared with 157 ± 50 compared with 60 ± 50 nmol/mL · 10 h; P < 0.05).

Discussion

Currently, most people living in the United States underconsume vitamin E from foods and beverages (6, 16). In addition to encouraging the consumption of vitamin E–rich foods, strategies to increase the absorption of vitamin E should be explored to help meet the body’s needs. Co-consuming dietary lipids promotes the absorption of fat-soluble nutrients (17, 18), but past research on vitamin E absorption was limited to assessing the effect of dietary lipids on the absorption of vitamin E supplements. For example, higher fat intake achieved by varying the fat content in milk increased the absorption of encapsulated α-tocopherol (8). The current study assessed the impact of an endogenous food source of lipids (11) on the absorption of vitamin E contained in a natural food matrix, raw vegetables. Our findings support that the co-consumption of cooked whole eggs is an effective way to increase the absorption of α-tocopherol and γ-tocopherol from raw mixed vegetables. Specifically, α-tocopherol and γ-tocopherol absorptions were ~7.5-fold and ~4.5-fold higher when the salad was consumed with 3 whole eggs (HE trial) than without eggs (CON trial).

**TABLE 2** Composite postprandial TG and total cholesterol responses of young men who consumed raw vegetables and/or whole eggs

<table>
<thead>
<tr>
<th>TRLs</th>
<th>CON$^2$</th>
<th>LE$^2$</th>
<th>HE$^2$</th>
<th>SWE$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG AUC$_{0-10}$ h, mg/dL · 10 h</td>
<td>12.7 ± 12$^a$</td>
<td>21.1 ± 12$^a$</td>
<td>79.8 ± 12.2$^a$</td>
<td>74.9 ± 13.3</td>
</tr>
<tr>
<td>Total cholesterol AUC$_{0-10}$ h, mg/dL · 10 h</td>
<td>1.7 ± 1</td>
<td>4.2 ± 1.2</td>
<td>5.3 ± 1.2</td>
<td>7.5 ± 3.6</td>
</tr>
</tbody>
</table>

1 Labeled means in a row without a common superscript letter differ, P < 0.01. AUC$_{0-10}$ h, 0- to 10-h AUCs; CON, control (raw mixed-vegetable salad without eggs); HE, high egg (raw mixed-vegetable salad with 150 g scrambled whole eggs); LE, low egg (raw mixed-vegetable salad with 75 g scrambled whole eggs); SWE, scrambled whole egg (150 g scrambled whole eggs without raw mixed-vegetable salad); TRL, TG-rich lipoprotein fraction.

2 Values are least-squares means ± SEs, n = 16.

3 Values are means ± SEs, n = 9.
The attribution of the higher postprandial vitamin E response in the HE trial compared with the CON trial to increased absorption of the vitamin E contained in the salad vegetables is confounded by eggs, which also contain vitamin E (19). Thus, we needed a way to distinguish between the absorption of vitamin E contained in the salad ingredients compared with that from the eggs alone. To address this issue we re-recruited participants for a fourth trial. The results showed that, when the salad and 3 eggs were consumed together (HE trial), the actual absorptions of α-tocopherol and γ-tocopherol were 1.6- and 0.6-fold higher than their corresponding predicted responses and the plasma responses of α-tocopherol and γ-tocopherol contained in the salad only were 8.0- and 2.2-fold higher than when the salad was consumed without eggs. These fold-change values support for the 1.7- and 2.1-fold higher α-tocopherol and γ-tocopherol absorptions, respectively, when 10.5 g (LE) compared with 6 g (CON) mixed-vegetable salad were consumed together with 150 g scrambled whole eggs; SWE, scrambled whole egg (150 g scrambled whole eggs without raw mixed-vegetable salad); TRL, TG-rich lipoprotein fraction.

**FIGURE 2** Baseline-corrected α-tocopherol (A) and γ-tocopherol (B) responses in TRLs in 16 young adult males who consumed raw vegetables without or with whole eggs. Values are least-squares means ± SEs. Labeled means at a time without a common letter differ, *P* < 0.05. CON, control (raw mixed-vegetable salad without eggs); HE, high egg (raw mixed-vegetable salad with 150 g scrambled whole eggs); LE, low egg (raw mixed-vegetable salad with 75 g scrambled whole eggs); TRL, TG-rich lipoprotein fraction.

**TABLE 3** Comparison between composite postprandial α-tocopherol and γ-tocopherol responses in young men who consumed raw vegetables without or with whole eggs1

<table>
<thead>
<tr>
<th>TRLs</th>
<th>CON</th>
<th>LE</th>
<th>HE</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-Tocopherol AUC$_{0-10}$ h, nmol/L · 10 h per milligram of α-tocopherol intake</td>
<td>56 ± 13</td>
<td>116 ± 25</td>
<td>303 ± 83*</td>
</tr>
<tr>
<td>γ-Tocopherol AUC$_{0-10}$ h, nmol/L · 10 h per milligram of γ-tocopherol intake</td>
<td>36 ± 10</td>
<td>88 ± 21</td>
<td>129 ± 94*</td>
</tr>
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</table>

1 Values are means ± SEs, *n* = 16. Labeled means in a column without a common superscript letter differ, *P* < 0.05. AUC$_{0-10}$ h, 0- to 10-h AUCs; CON, control (raw mixed-vegetable salad without eggs); HE, high egg (raw mixed-vegetable salad with 150 g scrambled whole eggs); LE, low egg (raw mixed-vegetable salad with 75 g scrambled whole eggs; SWE, scrambled whole egg (150 g scrambled whole eggs without raw mixed-vegetable salad); TRL, TG-rich lipoprotein fraction.

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with 3.0 g (CON) lipids were consumed with the salad is likely due to the small sample size and low statistical power. The same issue may have affected research in 20 participants, which showed that dairy lipids (7.9 compared with 0.2 g dairy lipids) did not significantly influence the absorption of α-tocopherol measured in plasma (not TRL) over a 72-h time period (31).

The current observation that the absorption of α-tocopherol (per milligram of dietary intake) was 1.3-fold higher than γ-tocopherol during the HE trial is consistent with an in vitro study in which the bioaccessibility of α-tocopherol was 2.7-fold higher than γ-tocopherol, assessed as the transfer from romaine lettuce (the food matrix) to micelles with a constant amount of dietary lipid (32). The presence of vitamin E hydroxylase in small intestine mucosa (33) may also partially contribute to the greater metabolism of γ-tocopherol, resulting in lower absorption of γ-tocopherol than of α-tocopherol. Past research in humans provided inconsistent results that α-tocopherol absorption was not different (34) or higher (35) than γ-tocopherol. But, these studies used higher doses [50 mg/dose (34) and 1000 mg/dose (35)] of encapsulated α-tocopherol and γ-tocopherol, which are ~1600% and 32,000% higher, respectively, than the ~3.2 mg of these vitamin E isoforms per dose consumed in the HE trial. More in vivo assessments of the apparent absorption of different vitamin E isoforms at physiologic doses and in natural food matrices are warranted in humans.

Strengths of this research include the novelty of assessing the impact of one food (eggs) on the absorption of a nutrient (vitamin E) contained in another food (salad) and including measurements of both α-tocopherol and γ-tocopherol. With regard to potential limitations, we are aware that there are several alternative ways of describing the postprandial vitamin E responses other than using the word “absorption.” We chose “absorption” as the descriptor because we specifically measured the α-tocopherol and γ-tocopherol concentrations within TRLs, which mainly represent newly absorbed dietary vitamin E appearing in plasma. One limitation of this research is that we only studied men, although our previous research showed that the absorption of fat-soluble nutrients, including carotenoids, was comparable between men and women (15). Another limitation may be that assessments of the absorption of α-tocopherol and γ-tocopherol were secondary analyses, not based on a priori hypotheses or with outcome-specific sample size estimates. In addition, the scrambled whole egg–only trial was done subsequent to the other 3 randomized trials after we identified the importance of including a trial to measure the absorption of α-tocopherol and γ-tocopherol from eggs. The lipids in egg yolk consist of neutral lipids (65%), phospholipids (31%), and cholesterol (4%) (36); and we recognize that phospholipids may also enhance vitamin E absorption (20). Thus, more research is needed to assess the specific impact of those components of egg yolk on vitamin E absorption.

In summary, the consumption of cooked whole eggs is an effective way to increase the absorption of α-tocopherol and γ-tocopherol from co-consumed low-fat foods that naturally contain vitamin E, such as a raw mixed-vegetable salad. Co-consuming cooked whole eggs with a vegetable salad improves the nutritional value of the vegetables, which are underconsumed by most of the US population (6, 16).

Acknowledgments
JEK, MGF, and WWC designed the research and analyzed the data; JEK conducted the research; and JEK and WWC wrote the manuscript and had primary responsibility for the final content of the manuscript. All authors read and approved the final manuscript.

References


