# Carotenoids, Immunocompetence, and the Information Content of Sexual Colors: An Experimental Test

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ABSTRACT: Many male birds use carotenoid pigments to acquire brilliant colors that advertise their health and condition to prospective mates. The direct means by which the most colorful males achieve superior health has been debated, however. One hypothesis, based on studies of carotenoids as antioxidants in humans and other animals, is that carotenoids directly boost the immune system of colorful birds. We studied the relationship between carotenoid pigments, immune function, and sexual coloration in zebra finches (*Taeniopygia guttata*), a species in which males incorporate carotenoid pigments into their beak to attract mates. We tested the hypotheses that increased dietary carotenoid intake enhances immunocompetence in male zebra finches and that levels of carotenoids circulating in blood, which also determine beak coloration, directly predict the immune response of individuals. We experimentally supplemented captive finches with two common dietary carotenoid pigments (lutein and zeaxanthin) and measured cell-mediated and humoral immunity a month later. Supplemented males showed elevated blood-carotenoid levels, brighter beak coloration, and increased cell-mediated and humoral immune responses than did controls. Cell-mediated responses were predicted directly by changes in beak color and plasma carotenoid concentration of individual birds. These experimental findings suggest that carotenoid-based color signals in birds may directly signal male health via the immunostimulatory action of ingested and circulated carotenoid pigments.

*Keywords:* cell-mediated immunity, humoral immunity, ornamental coloration, plasma carotenoids, sexual selection, *Taeniopygia guttata*, zebra finch.

Carotenoid pigments perform a diverse suite of physiological functions in living things, including cell membrane reinforcement in fungi, light harvesting in photosynthetic organisms, and photoprotection in the human eye (Vershinin 1999). Perhaps their most widely recognized function, however, is their antioxidant and immune-enhancing activity in a variety of animal systems, most notably humans (Burton 1989; Krinsky 1989). Because of their molecular composition, specifically their highly conjugated double-bond structure, carotenoids such as $\beta$-carotene and lutein serve as effective scavengers of the harmful unpaired electrons (e.g., singlet oxygens, free radicals) produced by normal metabolic processes that damage body tissues (e.g., via lipid peroxidation; Krinsky 1992). The cells of the immune system are particularly sensitive to oxidative stress and may benefit substantially from the free radical–trapping ability of carotenoids, as the immune response itself produces reactive oxygen species that disrupt the intercellular signals sent via lipid-rich, membrane-bound receptors (Chew 1993). An enormous body of literature has accumulated over the past 20 yr demonstrating the potency of carotenoids as antioxidants and immunostimulants in humans and other mammals (reviewed in Hughes 2001; Krinsky 2001).

Many nonmammalian animals, such as fishes and birds, also use carotenoid pigments to color their body red, orange, or yellow (Goodwin 1984). These integumentary colors in skin and feathers are often more elaborate in males and are used as sexual signals to communicate their quality as a prospective mate to females (Olson and Owens 1998). Because carotenoid pigments cannot be manufactured by vertebrates de novo and instead must be obtained from the diet, it has long been argued that carotenoid-based display colors function as reliable indicators of the foraging ability or nutritional state of individuals (reviewed in Hill et al. 2002). In fact, nutritional control over carotenoid pigmentation in fish scales and bird feathers and bare parts has been well established in a variety of species (Hill 1999*b*, 2002). However, within the last decade, it has also been suggested that these carotenoid-derived sexual colors may signal the health and condition of males because of the specific antioxidant and immunostimulatory activity of carotenoids obtained from the diet and transported through the body before they are incorporated into the integument

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(Lozano 1994; von Schantz et al. 1999; Møller et al. 2000). This issue continues to be debated on theoretical grounds (Hill 1999*a*; Lozano 2001), fueled by the idea that colorful birds and fishes obtain far more carotenoids in the diet than carotenoid-deprived mammals, and thus individuals may not be limited in the extent to which they can use carotenoids to boost their immune response.

The aim of this study was to investigate the ability of carotenoids to enhance the immune system in a bird species with ornamental carotenoid-based coloration. We studied the zebra finch (*Taeniopygia guttata*), a species that exhibits bright red carotenoid pigmentation in the beak and legs (McGraw et al. 2002). Male zebra finches display more colorful beaks than females, and females prefer to mate with the most colorful males (Burley and Coopersmith 1987; Houtman 1992; but see Collins and ten Cate 1996). Using a captive colony of male zebra finches, we performed a carotenoid-supplementation experiment in which we provisioned a group of birds with an extra dose of two naturally occurring dietary carotenoids—lutein and zeaxanthin (McGraw et al. 2002)—for a 4-wk period. After supplementation, we subjected treatment and control birds to two commonly used immune challenges: a phytohemagglutinin skin test (PHA) and a sheep red blood cell hemagglutination assay (SRBC), each of which assays a different arm of the immune system (cell-mediated immunity and humoral immunity, respectively). If carotenoids in these colorful finches play an immunostimulatory role, we predicted higher cell-mediated and humoral immune responses in pigment-supplemented birds compared to unsupplemented controls. We further investigated the immunological consequences of carotenoids by scoring the beak color of male zebra finches using reflectance spectrophotometry and by drawing blood from birds to characterize the types and amounts of carotenoid pigments circulating through blood (using high-performance liquid chromatography [HPLC]) that are available for deactivating potentially damaging free radicals. Here, we predicted that changes in the expression of beak color and the concentration of blood carotenoids in individual birds would directly relate to their immunocompetence. Change in carotenoid status is important in this context because, unlike raw values, it accounts for any undetected changes in health state not a part of this study (e.g., parasitism) that might require carotenoid allocation. Birds showing a recent increase in carotenoid status would be expected to mount the highest immune responses.

## Methods

### *Experimental Design*

Twenty male zebra finches were housed in separate cages in an animal-approved indoor room at Cornell University and fed an ad lib. diet of water and a commercial birdseed mix (Kaytee Forti-Diet; see McGraw et al. 2002 for additional housing details). In an earlier study of food intake, we determined that individual birds consume a range of 2–4 g/d of this food (McGraw et al. 2003), which amounts to an estimated 20–40 $\mu$g of ingested carotenoids daily. Ninety-five percent of all carotenoids in this seed mix are made up of the two major plant xanthophylls, lutein (78%) and zeaxanthin (17%; McGraw et al. 2002). Thus, we designed our carotenoid-supplementation study to manipulate the concentration of these two primary dietary carotenoids following these relative and absolute amounts, using water-dispersable lutein and zeaxanthin beadlets kindly supplied by Roche Vitamins (Parsippany, N.J.).

Our 20 cages of finches were randomly assigned to one of two treatment groups: carotenoid supplemented ($n = 10$ males), and carotenoid unsupplemented ($n = 10$ males). Supplemented birds received 9 $\mu$g lutein and 2 $\mu$g zeaxanthin/mL drinking water, whereas control birds received no carotenoids in water. In a pilot study, we found that birds drank 2–4 mL water/d; thus, the high-carotenoid group was receiving a dose approximately twice that of daily carotenoid intake. This proved to be a reasonable supplement, since circulating blood-carotenoid levels in provisioned zebra finches remained within the physiological range of control males during our study (see "Results"). Supplementation began on January 31, 2002, and continued through the 5-wk course of the experiment, which is sufficient time for dietary carotenoid supplementation to elevate blood-carotenoid levels in a host of animals (e.g., humans [Ringer et al. 1991] and domestic chickens [*Gallus domesticus*; Marusich and Bauernfiend 1981]).

### *Beak-Color Scoring and Blood Sampling*

We scored beak color and drew blood for plasma carotenoid and immunological analyses at three times during the study: (1) on the day before carotenoid supplementation (January 30, 2002); (2) 4 wk into the carotenoid supplementation and the day on which our immune challenges were initiated (February 27, 2002); and (3) 9 d after beginning these immune challenges (March 8, 2002). Beak color was measured using a handheld Colortron II reflectance spectrophotometer (Hill 1998). Following previous studies (McGraw et al. 2003), we scored the left and right sides of the maxilla and averaged these two measurements to determine bill hue, saturation, and brightness for each bird. These tristimulus measures were then collapsed into a single composite color score (PC1) using a principal component analysis. Note that, because of the Colortron's scoring system, lower PC1 scores correspond to redder beaks. We drew 50–100 $\mu$L of whole blood from each bird

through the alar vein into heparinized microcapillary tubes, and the plasma was centrifuged off and saved in 1.5-mL Eppendorf tubes at −80°C for later analysis.

### *Immune Measures*

We subjected all 20 captive zebra finches to two immune challenges after the 4-wk carotenoid supplementation: a PHA skin test and an SRBC hemagglutination assay. The PHA test assays an individual's mitogenic, T-lymphocyte responsiveness to a foreign plant protein (Smits et al. 1999). The SRBC assay measures the humoral response to T-dependent antigens (Higgins 1996). Both tests have been used previously and effectively in assaying cell-mediated and humoral immunity in zebra finches (e.g., Deerenberg et al. 1997; Birkhead et al. 1998; Ewenson et al. 2001) and other songbirds by the authors (European starlings *Sturna vulgaris* and tree swallows *Tachycineta bicolor*; D. Ardia, unpublished data) and in relation to carotenoid supplementation in humans (Kramer and Burri 1997) and mice (Jyonouchi et al. 1994).

To conduct the PHA test, one of us (D. R. Ardia) blind to the treatment groups measured the right wing web of each bird three times with a digital micrometer (to the nearest 0.05 mm) to obtain an average preswelling measurement and then injected this area with 0.15 mg of PHA-P (Sigma Chemical, St. Louis, Mo.) in 30 μL phosphate buffered saline (PBS; Hõrak et al. 1999). The birds were immediately placed back in their housing cages, and we returned 24 hr later, on February 28, 2002, to measure the swollen area. We present results as the difference between mean postinjection swelling and mean preinjection swelling (sensu Smits et al. 1999). Within-individual repeatability of wing-web swelling measurements was moderately high (preinjection: $R_i = 0.62$, $F = 4.73$, df $= 19, 20$, $P = .04$; postinjection: $R_i = 0.55$, $F = 3.65$, df $= 19, 20$, $P = .05$).

To perform the SRBC assay, we first drew blood (as above) on February 27, 2002, to determine background, preexposure levels to this antigen (from 20 μL plasma) and then injected each bird intra-abdominally with $5 \times 10^7$ sheep red blood cells (ICN Biomedicals, Aurora, Ohio) suspended in 100 μL PBS (sensu Deerenberg et al. 1997). Nine days later, on March 8, 2002, we returned to again draw blood from the finches to determine postexposure antibody titers in plasma. We waited 9 d postimmunization to sample blood because a previous study with zebra finches showed that responsiveness to this antigen peaked at this time (Birkhead et al. 1998). One of us (D. R. Ardia) determined antibody levels from 20 μL plasma using a base 2 serial dilution hemagglutination test (sensu Roitt et al. 2001). Samples were serially diluted starting with 20 μL PBS, and to each well we added 20 μL of a 2% suspension of SRBC in PBS. Plates were incubated at 37°C for 1 hr. Titers are given as the $\log_2$ of the reciprocal of the highest dilution of plasma showing positive hemagglutination. For each plate, we ran both a positive and negative control. Assays were run in duplicate, and we report averages here. Again, repeatabilities were moderately high for both sets of measurements (preexposure: $R_i = 0.60$, $F = 3.91$, df $= 19, 20$, $P = .03$; postexposure: $R_i = 0.65$, $F = 4.65$, df $= 19, 20$, $P = .01$).

### *Plasma-Carotenoid Analyses*

Methods for plasma-carotenoid extractions and HPLC analyses follow those described in McGraw et al. (2002, 2003). Zebra finches circulate four carotenoid pigments through blood, three of which are present in the diet (lutein, zeaxanthin, and β-cryptoxanthin) and one that is metabolically derived (2',3'-anhydrolutein).

### *Statistical Procedures*

Data were analyzed using the StatView 5.0.1 software package (SAS Institute 1998). We ran parametric statistical tests when data met the assumptions of normality and homoscedasticity; otherwise, we performed nonparametric tests. To investigate the effect of carotenoid treatment on beak color, plasma-carotenoid levels, cell-mediated immunity, and humoral immunity, we used unpaired comparisons (either *t*-tests or Mann-Whitney *U*-tests). We used correlational tests (Fisher's *r*-to-*Z* or Spearman's rank correlations) to compare the relationships between our two immune measures and changes in beak-color expression and plasma-carotenoid concentration for individuals over the course of the 4-wk pigment supplementation period.

## Results

### *Preexperiment Beak Coloration and Plasma Carotenoids*

Randomly assigned treatment groups did not differ in preexperimental beak color (unpaired *t*-test, $t = -1.27$, $P = .22$) or plasma carotenoid concentrations (overall and for each of the four types: all $-0.1 < t < -1.2$, all $P > .25$). Before the experiment, beak color and plasma carotenoid levels were significantly correlated in males (Spearman's rank correlation, $r_s = -0.44$, $P = .05$), as has been shown previously (McGraw et al. 2003). This relationship held up after the 4-wk carotenoid supplementation period as well ($r_s = -0.50$, $P = .02$).

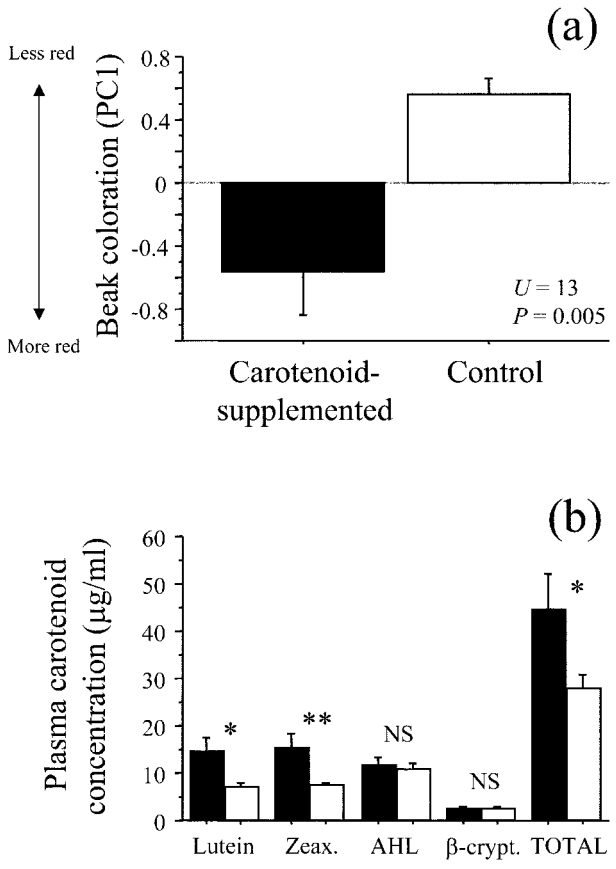


**Figure 1:** Effect of 4-wk dietary lutein and zeaxathin supplementation on (*a*) the expression of beak coloration and (*b*) the concentration of individual carotenoids in plasma of captive male zebra finches. Means ± SEM are provided. One asterisk = $P < .05$; two asterisks = $P < .01$; NS = $P > .6$. $n = 10$ for each treatment group shown here.

### *Effect of Carotenoid Supplementation on Beak Color and Plasma Carotenoid Levels*

After 4 wk of carotenoid supplementation, male zebra finches that were provisioned with dietary carotenoids had significantly more colorful beaks than control birds (fig. 1*a*). The effect of the supplementation is also represented by the significant difference in the change in beak coloration between the two groups, with provisioned birds developing substantially more red bills (unpaired *t*-test, $t = 3.88$, $P = .001$). This change in beak pigmentation occurred due to the increased circulation of carotenoid pigments through the blood. Carotenoid-supplemented males transported a higher concentration of plasma carotenoids than controls (fig. 1*b*). This was true for total plasma-pigment concentration and for levels of the two supplemented carotenoids only—lutein and zeaxanthin (fig. 1*b*). As with beak color, there also was a highly significant difference in the change in plasma-carotenoid levels during this experiment for the two treatment groups, with supplemented males showing large increases in blood-pigment concentration (change in total concentration: Mann-Whitney *U*-tests, $U = 6$, $P = .0009$; lutein: $U = 6.5$, $P = .001$; zeaxanthin: $U = 1.5$, $P = .0002$).

It should be noted that the range of carotenoid levels found in supplemented birds (13–82 µg/mL) closely matched that of control finches (13–75 µg/mL), indicating that our carotenoid-supplementation protocol did not generate pharmacologically high pigment levels in these birds. Moreover, these levels are comparable to those found in several wild carotenoid-pigmented birds (e.g., American kestrels [*Falco sparverius*], Bortolotti et al. 2000; lesser black-backed gull [*Larus fuscus*], Blount et al. 2002; range of species found in Tella et al. 1998), suggesting that our captive birds did not suffer from a carotenoid-deprived baseline diet.

### *Effect of Carotenoid Supplementation on the Immune System*

Carotenoid-supplemented males in our study showed superior immune performance for both of our measures of immunocompetence. Provisioned males mounted a significantly higher cell-mediated response to the novel plant protein PHA than controls (fig. 2*a*) and also produced increased antibody titers (humoral immunity) when challenged with SRBCs (fig. 2*b*).

### *Relationship between Immunocompetence, Plasma-Carotenoid Levels, and Beak Color*

Interestingly, plasma-carotenoid levels decreased during the 9-d period when individuals were immunologically challenged (within-individual paired *t*-test, $t = 2.94$, $P = .008$), even for carotenoid-provisioned males (who continued to receive the dietary supplement during this time; $t = 2.67$, $P = .025$), suggesting that these finches may have actively shunted carotenoid pigments from blood to mount immune responses. To further explore the process by which carotenoids affected cell-mediated and humoral immune performance during our study, we compared our two immune measures to recent changes in the levels of circulating blood carotenoids and beak-color expression in individual males. Cell-mediated responses to PHA were in fact significantly predicted by changes in both plasma-carotenoid levels ($r_s = 0.68$, $P = .003$) and beak coloration ($r_s = -0.61$, $P = .008$), with more colorful and pigmented males mounting higher responses (fig. 3). When broken down by treatment group, only the relationship between the change in plasma-carotenoid levels and PHA response in carotenoid-supplemented males re-

mained significant, although all other trends were in the predicted direction (fig. 3). We found no significant correlations between SRBC antibody titers and changes in either plasma-carotenoid concentration ($r_s = 0.19$, $P = .40$) or beak coloration ($r_s = -0.3$, $P = .19$).

We also compared the concentration of specific carotenoid types in blood to investigate whether there may be one specific plasma pigment that best served to stimulate cell-mediated immunity in zebra finches. Circulating levels of each plasma-pigment type are all significantly positively correlated in zebra finch serum (McGraw et al. 2003; this article), and in our lutein- and zeaxanthin-supplemented birds these two pigments were most highly correlated ($r = 0.98$, $P < .0001$). Both lutein ($r = 0.61$, $P = .05$) and zeaxanthin ($r = 0.62$, $P = .05$) were significantly correlated with PHA response in our 10 carotenoid-provisioned finches, but this was not true for anhydrolutein or $\beta$-cryptoxanthin (both $P > .4$).

## Discussion

For decades, evolutionary biologists have theorized that ornamental traits in animals, such as elaborate courtship dances, large antlers or horns, and beautiful colors, should serve as reliable indicators of general health and condition to conspecifics, as they are in some way costly to produce and can only be exaggerated to the fullest extent by the healthiest, highest-quality individuals (Zahavi 1975; Grafen 1990). While there is now evidence that many of these ornate features indeed serve as honest advertisements of health and immune state (Møller et al. 1999), it is still unclear in many cases how these sexual traits reveal immune performance or specifically what aspects of ornament production and display are linked to fighting off pathogens and parasites. Carotenoid-based color signals, in contrast, provide a valuable system in which to investigate why sexual ornaments may indicate immunocompetence, because the very pigments used to become colorful may themselves serve important health functions.

Across a range of fish and bird species, carotenoid-based sexual signals reveal nutritional state and levels of parasitic infection (reviewed in Møller et al. 2000) and are correlated with immune function (e.g., Skarstein and Folstad 1996; Bortolotti et al. 2000; Saks et al. 2003). In this study, we used dietary carotenoid supplementation to experimentally examine the relationship between carotenoid availability, ornamental beak coloration, and immunocompetence in male zebra finches. We found that male finches provisioned with a dose of two naturally occurring seed carotenoids—lutein and zeaxanthin—circulated more of these carotenoids in blood, developed more brightly colored beaks, and showed elevated cell-mediated and humoral immune responses. Moreover, individual levels of cell-mediated immunity among carotenoid-treated birds were significantly predicted by changes in the concentration of blood carotenoids and the expression of beak color, with males becoming more red and accumulating more plasma carotenoids mounting the highest T-lymphocyte responses. Altogether, these findings are consistent with the hypotheses that carotenoids can be limited in the diets of colorful birds, that they function to stimulate two different arms of the immune system in male zebra finches, and that carotenoid-based color signals can indicate the health state of individuals via the immunoenhancing action of carotenoid pigments.

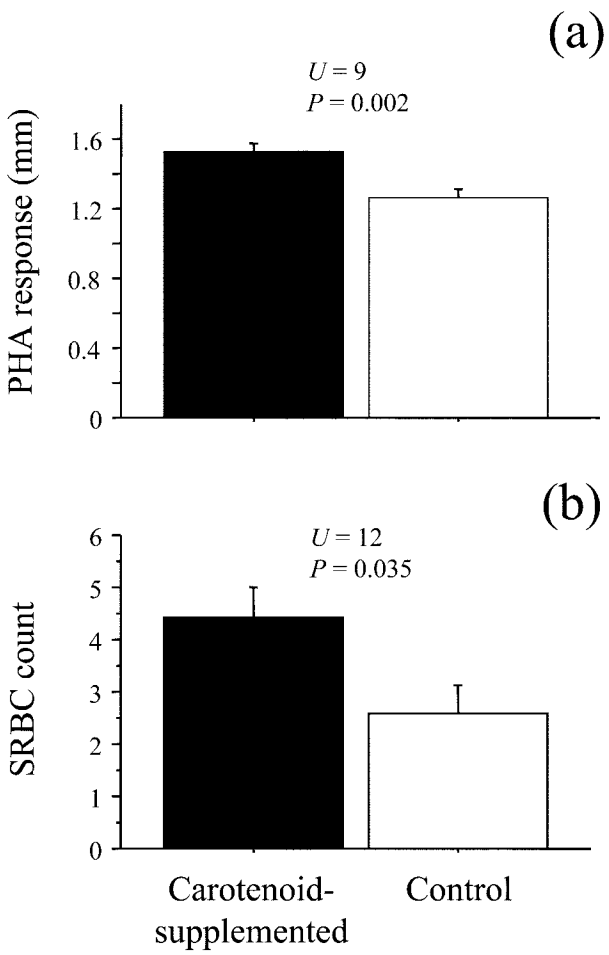


**Figure 2:** Effect of carotenoid supplementation on the (*a*) cell-mediated and (*b*) humoral immune response of male *Taeniopygia guttata*. Means ± SEM. Cell-mediated immunity was assayed using the phytohemagglutinin skin test, whereas humoral immune responses were measured using the sheep red blood cell hemagglutination assay. $n = 10$ for each treatment group shown here.

Our results are also consistent with two other experimental studies that have investigated the immunological

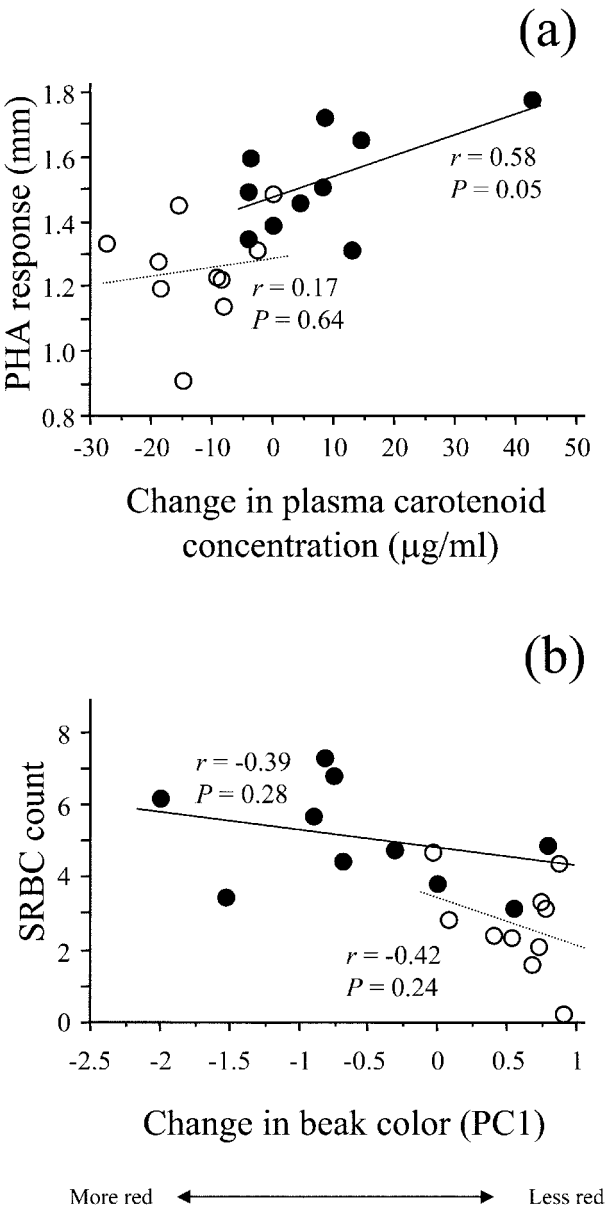


**Figure 3:** Scatterplot illustrating the relationship between cell-mediated immune performance and (*a*) change in total plasma-carotenoid concentration and (*b*) change in carotenoid-derived beak coloration in male zebra finches. Following previous conventions, open circles denote control birds, solid circles represent treatment birds. Regression lines (with 95% confidence) and the associated test statistics are shown for each treatment group; *solid lines* = supplemented males, *dashed lines* = control males. $n = 10$ for each treatment group shown here

benefits of increased carotenoid intake in colorful birds. Fenoglio et al. (2002) supplemented common moorhen chicks (*Gallinula chloropus*) with an artificial colorant (canthaxanthin) and found that carotenoid treatment elevated cell-mediated immunity (as measured by the PHA skin test). Blount et al. (2003) also recently used similar xanthophyll-supplementation and PHA-injection protocols to the one used here to demonstrate superior cell-mediated immune performance by carotenoid-enriched male zebra finches. Colorful fish, such as rainbow trout (*Oncorhynchus mykiss*), show comparable increases in cell-mediated (e.g., phagocytosis, nonspecific cytotoxicity) and humoral (e.g., serum complement, lysozyme activity) immune performance when provisioned with dietary carotenoids (Amar et al. 2000). Supplementation studies with juvenile parrotfish (*Oplegnatus* sp.; Tachibana et al. 1997) and domestic chicks (Haq et al. 1996) also illustrate the immunoenhancing ability of carotenoids.

We investigated in greater detail the specific biochemical mechanisms by which carotenoid-replete males achieved higher immunocompetence in this study. First, because a variety of carotenoid pigments are usually present in animal diets (Goodwin 1980), we considered the immunostimulatory properties of different carotenoids in the body; $\beta$-carotene is usually thought of as the main carotenoid antioxidant in human diets (Burton 1989), but lutein or zeaxanthin can also elevate immune function in humans (Gerster 1993) and other mammals, such as cats (Kim et al. 2000*b*), dogs (Kim et al. 2000*a*), and mice (Chew et al. 1996). We found that, while zebra finches experienced a significant immune boost when supplemented with lutein and zeaxanthin, there was a positive relationship between actual blood levels of these two xanthophylls in individuals and one of our immune measures (PHA response). This suggests that lutein and zeaxanthin served as the potent immune-enhancers in this study (and not a related increase or decrease in other blood carotenoids), although we cannot distinguish between the relative effects of these two pigments on immunocompetence at this time. Nevertheless, because we expect that these two compounds are ubiquitous in the diets of herbivorous, granivorous, and even insectivorous birds, it is possible that the xanthophyll-related immune advantages documented in this study are widespread throughout the avian class.

Second, we considered the means by which carotenoids were allocated in the body once birds were subjected to immune challenges. The hypothesis that birds face a trade-off when shunting carotenoids to immune function versus ornamental coloration (Lozano 1994) hinges on the assumption that a compromised health state reduces carotenoid pools available for pigmentation. For example, Faivre et al. (2003) noted that subjecting a colorful songbird (the European blackbird *Turdus merula*) to a humoral challenge can impair carotenoid status (as measured by fading of beak color). Here, we found that levels of carotenoids circulating through blood were depressed after birds were injected with novel antigens/mitogens. This was

true even for males receiving the above-baseline carotenoid supplement, which suggests that birds may in fact use plasma carotenoids directly to help mount immune responses and consequently suffer in their ability to maintain bright integumentary coloration. In support of this, Koutsos et al. (2003) recently found that chickens actively shunt carotenoids to immune tissues (e.g., thymus, bursa) in direct relation to their blood-carotenoid status.

The health benefits of carotenoid pigments were first elucidated in mammals more than 70 yr ago (Green and Mellanby 1930), and carotenoids continue to be touted today as potential treatments for human illnesses such as macular degeneration, cardiovascular disease, and a number of forms of cancer (Rock 1997; Cooper et al. 1999). These decades' worth of human research have helped pave the way for our current interest in and understanding of the functions of carotenoid-based ornamental features in animals such as birds and fishes. While it is abundantly clear that carotenoid display colors can be indicative of an individual's access to colored pigments in the diet and its ability to physiologically incorporate these carotenoids into the integument (Hill et al. 2002), our study supports the notion that these carotenoid-dependent signals can also reveal the immunological state of animals, specifically because of the direct immunostimulatory action of carotenoids available in the body. Until now, this hypothesis has remained relatively unaccepted in the literature (Shykoff and Widmer 1996; Lozano 2001), perhaps because a vital argument has been overlooked in the debate over whether birds and fishes acquire carotenoid levels far in excess of what is required by their immune systems. Along with their increased dietary carotenoid supplies (Hill 1999*a*), colorful birds and fishes have incredible demands for carotenoids to be used in their integumentary displays. Unlike mammals, which do not incorporate large concentrations of carotenoid pigments into skin or hair, zebra finches, for example, maintain brightly pigmented beaks and legs throughout the year and must actively deliver carotenoids to this metabolically active and quickly growing tissue on a daily basis. Hence, the need to balance carotenoid allocation to physiological functions and morphological features is still great, and our experiment suggests that only those male finches with the highest access to carotenoids in the diet and in circulation can best devote pigments to the immune system to fight infections while simultaneously shunting enough to the integument for bright pigmentation.

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