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A Dietary Strategy for Optimizing the Visual Range of Athletes

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HARTH, J.B., L.M. RENZI-HAMMOND, and B.R. HAMMOND. A dietary strategy for optimizing the visual range of athletes. *Exerc. Sport Sci. Rev.*, Vol. 51, No. 3, pp. 103–108, 2023. *Visual range is quantified by assessing how far one can see clearly (an ability crucial to many athletes). This ability tends to vary significantly across individuals despite similar personal characteristics. We hypothesize that the primary driver of these differences is the individual response to scattered short-wave light in the environment moderated by the dietarily derived retinal pigments lutein and zeaxanthin.* **Key Words:** visual range, visibility, macular pigment, carotenoids, diet, athlete

Key Points

- Two specific carotenoids (lutein and zeaxanthin, L and Z) are known to be particularly important to nervous system health, in general, and visual-motor performance.
- Empirical data have shown that these pigments can improve chromatic contrast, decrease glare disability/discomfort, and speed recovery from photostress.
- This review focuses on the effects of L and Z on seeing objects in the distance (visual range) particularly under adverse conditions (such as interference by blue haze).

INTRODUCTION

A number of techniques typically are used to characterize human visual abilities. Such techniques differ between clinical settings, where time is limited and technicians perform many of the measurements, and research settings, where time is less limited and ease of use of the technology is less of a factor. Visual functions that are directly assessed in both settings, albeit differently, commonly include color discrimination, spatial vision (*e.g.*, contrast sensitivity functions and acuity), and temporal vision (dynamic acuity or motion perception), among many others. These assessments largely are familiar to clinicians and have been extensively validated and standardized (1). As reviewed by Bennett and colleagues (2), however, the most common sensory tests often do not reflect the kind of challenges many people face after leaving the clinic or laboratory, partly because of limitations on time and technology that exist within a clinic space. This issue particularly affects professional athletes whose performance is often limited by the extremes of their sensory capabilities. One such capability, very rarely measured, is visual range. All other things being equal, how far one can see outdoors varies greatly (3). Even individuals of the same age, health, and refractive status have significantly different visual range abilities (4,5). The ecological conditions under which an athlete, such as an outfielder, sees an object, such as a baseball, at a distance are quite different than, say, viewing a Snellen acuity chart in a clinic.

Ecologically valid assessments of visual range have been made outside the clinic, primarily by the military (4) or in the context of meteorology (*i.e.*, applications where actual visual range assessment is critical). In an early meteorological review on the physical conditions controlling visibility through the atmosphere, Bennett (6), for instance, detailed the atmospheric conditions that determine meteorological optical range as the intrinsic visibility of an object, tempered by “obscuration” from the atmosphere. Middleton (7) expanded these to include how these atmospheric conditions interact with the eye of the observer, given an observer’s adaptive state. Walls and Judd (8) expressed it in this way: intraocular filters absorb “blue haze,” sharpen the visual image, and extend vision “through long air pathways” (so-called airlight). A schematic of this hypothesis is shown in Figure 1.

Atmospheric Optics and Blue Haze

Atmospheric haze is a major monocular cue for judging the depth of items at a distance. This haze, which obscures objects in the distance, is caused by the monotonic increase in air turbidity due to aerosols suspended in the atmosphere (such as

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Accepted for publication: April 12, 2023
Editor: Stella Lucia Volpe, Ph.D., RDN, ACSM-CEP, FACSM.

0091-6331/5103/103–108
Exercise and Sport Sciences Reviews
DOI: 10.1249/JES.0000000000000318

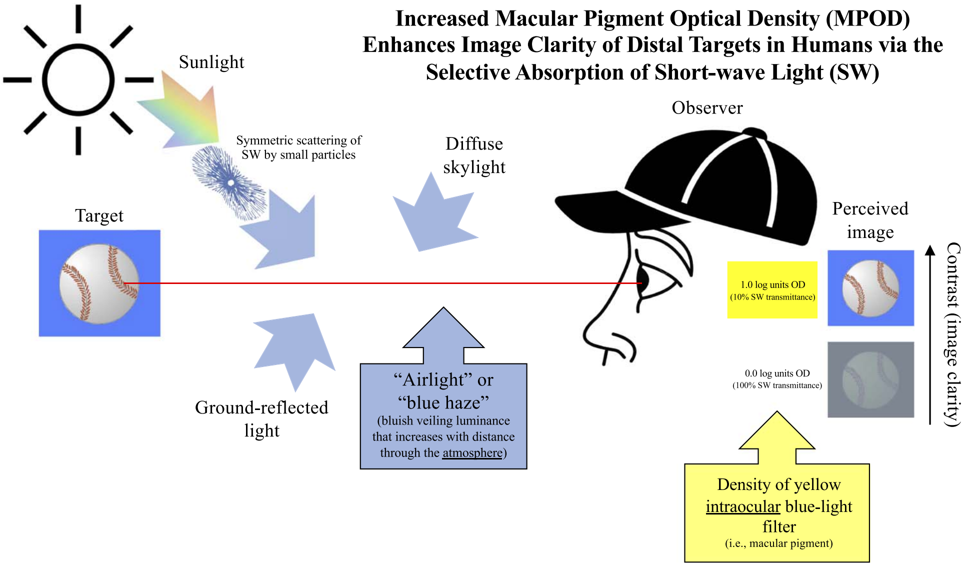

Figure 1. A schematic illustrating the primary hypothesis of the manuscript: increasing retinal L and Z increases visual functions that are a benefit to athletes, particularly visual range.

oxidized particulates (7)). These particulates interrupt and scatter light. The amount of light scatter, and which wavelengths are scattered, both depend on the radius, refractive index, and concentration of the particles present in the atmosphere. Often this results in a veiling haze that appears blue to an observer. This hue is a result of the preferential scattering of short-wave light, which is more energetic and prone to scatter. There are more aerosols (in this case, hydrocarbon particles released by vegetation) in the path of light as the distance between an object and an observer increases, so the longer the light path, the more visually apparent the haze becomes. The human visual system uses this as a monocular cue for depth, localization, and "image understanding" in outdoor environments (9), but this blue haze also obviously affects image clarity and contrast. Short-wave absorbing filters (like the Tiffen Haze filter) are used on cameras/telescopes under hazy conditions for this reason (10). Blue-light filtering (BLF) spectacle filters (that often appear yellow) have been shown empirically to improve the detection of distant targets by absorbing short-wave light (11,12). For example, BLF goggles long have been recommended for skiers (13) and have been shown to reduce adverse events due to irregularities in rough terrain (14).

Evolutionary Importance of Visual Range

It is doubtless the case that an ability to see well at a distance was an important trait for the successful evolution of our species. Refractive issues such as myopia were, likely, vanishingly rare for most of human evolution (15). Extending visual range would allow young, healthy individuals to better find food such as colorful fruits and plants and avoid predation that could even come from the sky. Seeing a predator from a distance increases the chance of successful avoidance, escape, and subsequent survival.

Many traits that likely evolved to promote survival also facilitate modern activities related to functions such as transportation, socialization, and leisure, including sports. This is particularly true when considering vocations or hobbies that impose visual and motor challenges such as professional athletes (16) or aircraft pilots. Many sports and active professions also are dependent on these traits sculpted by early evolutionary pressures.

Individual Differences in Visual Range

Lord Rayleigh, for whom Rayleigh scattering (which gives the sky its blue hue) is named, was the first to formally model light scattering. Went (17) attributed blue haze over forests to volatile organic compounds like terpenes (*e.g.*, the "blue" mountain ranges in Jamaica, New South Wales, Sydney Australia, Oregon, and Tennessee). Scientists have extensively investigated light scattering and blue haze as part of the physical sciences from atmospheric, particulate, and ecological perspectives. These environmental conditions, however, also create the stimulus conditions that form the first step in seeing.

Seeing objects at a far distance, whether one stands on a mountaintop or at home plate on a baseball diamond, often requires the ability to see a relatively small, indistinct image veiled by haze. Even if the object does not appear colorful (individuals apparently have very little awareness of actual color variations under real-world conditions (18)), the veil is often short-wave (blue) dominant. Ginsburg and colleagues assessed Air Force pilots' ability to detect incoming aircraft from the ground in a wide variety of air quality conditions, using detection distance as a measure of visual range (4). Ginsburg and colleagues noted that the visual acuity of the 10 pilots was, on average, 0.68 min arc (~20/15 Snellen acuity) with very little variation (SD = 0.06). Nonetheless, when tested under the same 10 environmental conditions, these otherwise highly homogenous subjects demonstrated dramatic variation (an average 29% variability) in their range of detection distances (see Table 1). Howell (5) also tested aircraft detection distance and found 37% variability in pilots' detection distance of incoming aircraft. Athletes represent another population with similarly homogenous characteristics, and it follows that detection distance would also significantly vary among athletes, despite comparable age, health, and visual acuity.

These field observations were tested directly in a controlled laboratory setting by measuring contrast sensitivity functions

TABLE 1. A selection of the data on visual range differences in pilots collected by Ginsburg and colleagues (4)

Meteorological Range (Miles)	Longest Detection Distance (Miles)	Shortest Detection Distance (Miles)	Detection Distance Range (Miles)	Variability (%)
2	1.15	0.73	0.42	37%
15	9.61	7.69	1.92	20%
13	11.8	9.24	2.56	22%
7	5.99	4.6	1.39	23%
3	0.48	0.29	0.19	40%
15	14.5	7.97	6.52	45%
15	7.51	5.5	2.01	27%
7	5.5	4.38	1.12	20%
15	8.77	6.42	2.37	27%
15	9.97	6.69	3.28	33%
				Average variability = 29%

Note the differences in pilot detection range while in the same environmental context (*i.e.*, the same lighting and air quality conditions).

(CSF) in a complex optical system that simulated the veiling effects of blue haze ((19); see also (20)). Twelve young healthy subjects with good acuity were tested. As shown in Figure 2 of Fletcher *et al.* (19), despite the highly controlled conditions, and the homogeneity of the subjects (young healthy adults with visual acuity better than 20/40), the CSF measured under haze conditions varied by a factor of six. This is summarized in Table 2. These empirical data are consistent with modeling studies of the effects of blue haze on a standard CSF (22–24).

Factors Influencing Individual Differences in Visual Range

Laboratory and field studies showing wide individual differences in visual range despite similar personal characteristics raise the question, what factors determine such differences? Even the young healthy eye likely varies among many dimensions that would be hard to assess in a typical clinical examination (1,24). One clue perhaps is to look at animals who must see fine small objects at a distance such as birds (*e.g.*, hawks seeing mice from high elevation). Birds integrate colored pigments (carotenoids) in the oil droplets anterior to their photoreceptor outer segments that influence many functional aspects of the bird's vision (8). Many animals, especially those under high light stress (*e.g.*, prairie dogs) or those that must see through turbid media (like fish), incorporate intraocular filters to improve visual function. Humans have adopted a similar strategy both purposefully and by evolutionary design. Nike, for example, created a line of tinted contact lenses (Maxsight ®) matched to various sports (25). This mimics a natural strategy.

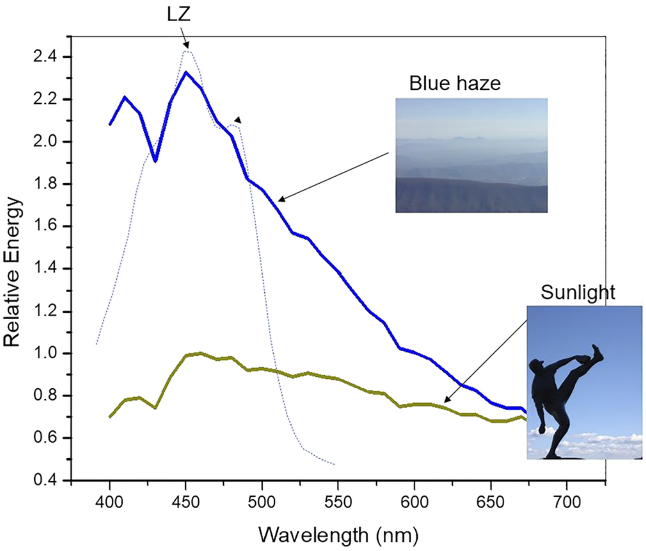

Figure 2. The absorbance spectrum of L and Z compared with the spectrum of skylight and blue haze (21). Notice the strong overlap between L and Z absorbance and the blue haze spectrum.

In the center of the human retina (the macula) is a blue-absorbing intraocular filter called macular pigment (MP). These yellow pigments are found most densely in the inner layers of the central retina (in and around the fovea), lying anterior to and screening mostly cones (8,16). They are accumulated through dietary intake of the carotenoids lutein (L) and zeaxanthin (Z) (and meso-zeaxanthin, an isomer of the conversion from L to Z *in situ*), pigments found in green leafy vegetables, yellow egg yolk, and colored fruits (26). These pigments, collectively known as MP, have an absorbance spectrum that closely matches the peak of blue haze measured in the atmosphere (see Fig. 2).

Fletcher and colleagues (19) measured contrast sensitivity under blue haze conditions in a separate sample of 25 subjects but only at 8 cycles/degree. These subjects also had MP optical density (OD) measured psychophysically: the measures of MP and contrast sensitivity under haze conditions were strongly related ($r = 0.60$, $P < 0.002$). Hammond *et al.* (20) measured CSF with simulated haze and created an extrinsic filter that simulated differences in MPOD. They found that artificially increasing MPOD led to an improvement of contrast sensitivity thresholds under haze conditions by up to 35% (nearly identical to the MPOD effects on haze original modeled by Wooten and Hammond (22)). A dietary intervention that increases fruit and vegetable intake in athletes can enable analogous endogenous increases in MPOD — possibly aiding their visual range ability and subsequent athletic performance.

MP is one of the more visibly obvious features of the central human retina. MPOD can be reliably and noninvasively

TABLE 2. Area under the curve values for CSF measured under blue haze conditions for 12 young healthy subjects (derived from (20))

	N	Minimum	Maximum	Mean	SD
Integral value	12	966	5929	4025	1421

The range in these young healthy adults with similar refraction is approximately a factor of 6.

measured using a variety of physical methods, such as autofluorescence, and psychophysical methods, such as heterochromatic flicker photometry (27). Measurements using these methods have shown that MPOD is highly variable among individuals (24), and numerous studies have examined the functional consequences of these large variations (16). Since L and Z are found throughout the eye and brain (28), their effects tend to be far reaching. Generally, however, MP's effects can be separated into two major categories: those pertaining to protection from age-related disease and those pertaining to improved function.

With respect to improved function, the preferential absorption of short-wave light likely contributes to the mitigation of a range of deleterious effects of bright lights, like glare disability and photostress, while enhancing contrast (29). The visibility hypothesis (first proposed by Walls and Judd (8) and later refined by Wooten and Hammond (22)) falls in this functional category linking MPOD directly to improved vision outdoors.

Influence of Diet

Most prehistoric diets were largely plant-based and likely contained a variety of carotenoid-rich foods (30). Le Marchand and colleagues (31) studied the dietary habits of indigenous Fijians and found that their average intake of L and Z was approximately 24,000 mg/d. This is contrasted with the common American diet where L and Z intake is approximately 1000 μg/d (26). Various empirical studies have shown a direct link between dietary intake of L and Z and MPOD levels (32): when intake is high, MPOD is also high. For example, at 460 nm, the peak wavelength of sky-light, over 90% of blue light can be filtered before reaching the photoreceptors (the system compensates for such absorbance by increasing gain (33)). The competition and travel schedule of many elite athletes means that, like most Americans, however, their intake of carotenoid-rich foods is very low (34).

In Figure 3, we show MPOD data collected on a large sample (age range, 19–92 years; n = 1306) using the same measuring instrument (35) and stimulus conditions collated from the Southwest (36), Midwest (37), and Southeast (38) regions of the United States. As shown in the figure, the average MPOD based on these measuring conditions (1-degree diameter stimulus, 460 nm peak wavelength) is 0.26 (SD = 0.16; range = 0–0.13).

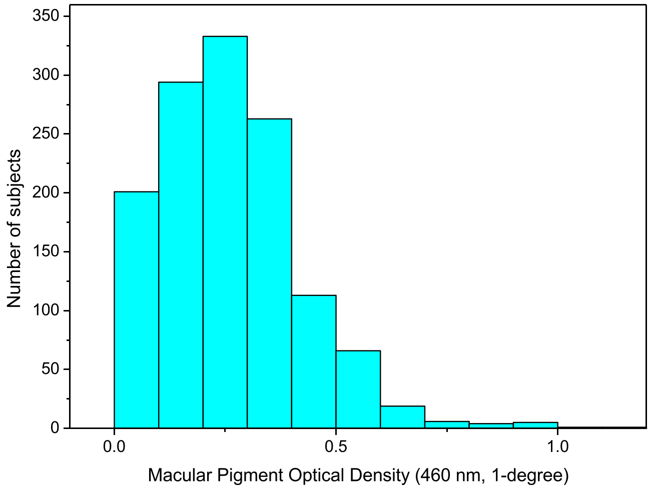

Figure 3. Macular pigment optical density data sampled from various regions across the United States (measured using the same stimulus conditions and model of instrument). Note that a good proportion of these data came from samples collected over 20 years ago. There is some evidence that, since L and Z supplements were introduced to the market, and awareness has increased, so too has MP density (more recent averages tend to be higher (29)).

If everyone had high levels of MPOD, as may have been true for much of our evolutionary history, then the issue of MP's effects on visual function would be of purely academic interest. We know, however, that average levels in the retina reflect the average low levels in the typical diet, including most athletes (34). This implies that many athletes who perform in environments with high levels of short-wave light are seeing at a level below their optical potential, and that athletes regardless of their environment may not be living up to their visual potential in other categories of function that MP affects.

Since the pigments can be delivered via supplements, and levels in the retina can be noninvasively monitored, blinded randomized trials comparing the effects of L and Z supplementation with those of inert placebos have been conducted (39,40). The effects that were studied ranged from those that were more centrally mediated (*e.g.*, reaction time, visual-motor function, executive cognition) to those mostly mediated by the eye itself (*e.g.*, glare disability/discomfort, photostress, chromatic contrast, and visibility/visual range). Many of these functions obviously translate to sports performance (16).

Increasing MP as a Strategy for Improving Visual-Motor Performance

In the mid-2000s, two different studies testing two different, relatively large samples with participants ranging in age from their late teens to their 80s demonstrated the same thing: people with higher MPOD process information faster (39,41). This result has since been supported by studies of specialty populations such as children (42). In 2013, Renzi and colleagues (43) formalized the neural efficiency hypothesis for MP, which suggested that higher MPOD (and, consequently, higher L and Z levels in the central nervous system (CNS) (28)) relates to a number of visual and motor functions in part by improving efficiency of processing. In support of this hypothesis, Renzi and colleagues (44) showed that participants across the lifespan with higher MPOD had better balance ability, reaction time, and coincidence anticipation ability, or the ability to coincide a movement (such as swinging a bat) with a visual stimulus (the ball at the correct location). Of course, all these functions contribute to sports performance. The determinates of success in athletic competitions are often at the millisecond level, where even small differences in processing efficiency account for meaningful differences in performance.

To test the hypothesis that performance can be improved by increasing L and Z in the CNS (retina and brain), Bovier and colleagues (39) conducted a double-blind placebo-controlled study on the effects of 4 months of L and Z supplementation on young and healthy individuals. Bovier and colleagues (39) found that despite the young and healthy sample whose brains tend to already operate at peak efficiency, supplementing a formulation containing L and Z, compared with placebo, resulted in improved visual processing speeds, coincidence anticipation, and reaction time. The brain of an athlete, often also young and healthy, could similarly benefit despite its apparent efficient operation, as improvements in these measured abilities could dramatically influence and bolster athletic performance. Moreover, several neuroimaging studies have shown that many higher-order effects of L and Z are tied to direct effects of these carotenoids on brain tissue itself (40).

Visual Range Issues for Modern Athletes

Studies aimed at understanding how L and Z affect the brain are relatively recent. The oldest idea for the function of these pigments (8), and perhaps, the one tied most directly to our interaction with the environment, is how these pigments influences the apprehension of distal stimuli. Although blue haze is most often associated with the off-gassing of vegetation, it is exacerbated by many aspects of modern life, particularly pollution (45). This means visual range can be limited even in areas that are not heavily forested. For example, heavy use of fertilizer increases the nitrous oxide emission on golf courses (45) possibly increasing air turbidity at times when a golfer is trying to site a distant hole. Such issues are often not assessed, but sometimes quantifying haze is critical. Pilots, for instance, must have a clear view of the landing runway (referred to as runway visual range, RVR) for both precision landing and takeoff. This distance, originally estimated by airport personnel, is now measured using a device called a diffusiometer, which measures light scatter within air to estimate horizontal visibility; for example, a tranmissometer uses a long throw collimated laser with a receiving detector and measures atmospheric extinction coefficients. Of course, these devices rely on external measures of atmosphere and generally ignore the large individual differences that likely exist across the pilots themselves (24).

Measuring RVR reflects a common challenge in many categories of sports: seeing objects clearly at a distance through long pathways of air-light. Long range shooting requires hitting targets at such a distance (~1000 yards) that atmospheric conditions become critical. This is true in shooting competitions, but also in hunting where natural camouflage often minimizes the contrast of a target from its background. Yellow shooting glasses/goggles commonly are used for this reason and invariably absorb short-wave light. American football athletes frequently use tinted visors on their helmets, whereas baseball athletes, beyond just the use of tinted contact or spectacle lenses, utilize a variety of tools (*e.g.*, brimmed hats, eye black, and webbed gloves) to aid in their handling of light stress from the sun or stadium lights. With so little time to judge ball trajectory (*e.g.*, a pop fly at approximately 150 ft hanging for approximately 5 s), outfielders, in particular, must have exceptionally clear distance vision (a similar challenge is faced in many watersports due to specular reflections from the surface of the water).

Short-wave light not only reduces distal visual function, but it can also impact function pertaining to the perception of (and response to) a proximate target. For instance, short-wave light is associated with the production of glare, heightened indices of subjective and physiological discomfort, and increased time necessary to recover sight of a target after the presentation of a photostressor (29). Through its selective filtration of short-wave light, MP has the potential to also benefit a host of other visual functions (*e.g.*, the reduction of glare discomfort or disability, the enhancement of chromatic contrast, or even contrast sensitivity under intense light conditions (29,46)) that impact visual-motor ability at close range or indoors. Traditional athletic competitions often require the vision of distal targets outdoors, but the adaptation of these events to modern settings (*e.g.*, domed/indoor venues, virtual reality training) and the advent of electronic sports (*e.g.*, video gaming, drone racing) have altered both the competitive environment and the related determinants of success.

In the context of an electronic sport competition, higher levels of MPOD could improve the visibility of a digital target through the selective absorption of short-wave light. LED monitors are primarily used in electronic sports due to their low response time and high refresh rate, but they produce higher intensities of blue light relative to other portions of the visible spectrum and emit higher relative energy of blue light compared with other types of monitors (47). Electronic sport athletes have commonly adopted the usage of blue light filters while competing — built into monitors or worn as spectacle lenses. The filtration of an LED monitor's blue light by an athlete's MP does not reduce the visual capabilities of the athlete (due to an increase in perceptual gain) and can effectively mitigate the discomfort or disability associated with its prominent presence. Modern athletes performing indoors are often exposed to nearby bright lights (*e.g.*, camera flashes, LED screens, stadium floodlights), and increased MPOD also has the potential to reduce the impact of these stimuli on athletes' performance.

CONCLUSIONS

Small improvements in visual ability can produce significant performance advantages in athletic competitions; increasing MPOD through dietary changes can produce significant improvements in visual range, among other abilities relevant to sports. Hammond *et al.* (20) used specialized optical equipment to measure contrast sensitivity under simulated blue haze conditions. They then used an extrinsic L and Z solution to add 0.5 MPOD to five young healthy subjects' natural MPOD. They found in this within-subject study that peak contrast sensitivity increased by approximately 30%. Contrast sensitivity, as measured by Hammond and colleagues (20), may be one of the better predictors of sports performance (48) and small improvements in CSF likely lead to large performance gains. The high activity level of athletes often means that they can eat poorly without weight gain (34). If MPOD does lead to better outdoor vision, it is likely that many athletes across a range of outdoor sports see less well than they could. A benign and relatively low effort dietary intervention would be simply to eat more carotenoid-rich foods (optimally consuming above 6 mg of L and Z per day). Increasing retinal and brain levels of L and Z would improve visual and cognitive performance while protecting athletes from a range of common injuries ranging from actinic eye and skin damage (49) to brain injury (50).

Acknowledgments

No external funding received. Authors declare no conflicts of interest.

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