

The Effects of Coffee and Napping on Nighttime Highway Driving

A Randomized Trial

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Background: Sleep-related accidents often involve healthy young persons who are driving at night. Coffee and napping restore alertness, but no study has compared their effects on real nighttime driving performances.

Objective: To test the effects of 125 mL of coffee (half a cup) containing 200 mg of caffeine, placebo (decaffeinated coffee containing 15 mg of caffeine), or a 30-minute nap (at 1:00 a.m.) in a car on nighttime driving performance.

Design: Double-blind, randomized, crossover study.

Setting: Sleep laboratory and open highway.

Participants: 12 young men (mean age, 21.3 years [SD, 1.8]).

Measurements: Self-rated fatigue and sleepiness, inappropriate line crossings from video recordings during highway driving, and polysomnographic recordings during the nap and subsequent sleep.

Intervention: Participants drove 200 km (125 miles) between 6:00 p.m. and 7:30 p.m. (daytime reference condition) or between 2:00 a.m. and 3:30 a.m. (coffee, decaffeinated coffee, or nap condition). After intervention, participants returned to the laboratory to sleep.

Results: Nighttime driving performance was similar to daytime performance (0 to 1 line crossing) for 75% of participants after coffee (0 or 1 line crossing), for 66% after the nap ($P = 0.66$ vs. coffee), and for only 13% after placebo ($P = 0.041$ vs. nap; $P = 0.014$ vs. coffee). The incidence rate ratios for having a line crossing after placebo were 3.7 (95% CI, 1.2 to 11.0; $P = 0.001$) compared with coffee and 2.9 (CI, 1.7 to 5.1; $P = 0.021$) compared with nap. A statistically significant interindividual variability was observed in response to sleep deprivation and countermeasures. Sleep latencies and efficiency during sleep after nighttime driving were similar in the 3 conditions.

Limitations: Only 1 dose of coffee and 1 nap duration were tested. Effects may differ in other patient or age groups.

Conclusions: Drinking coffee or napping at night statistically significantly reduces driving impairment without altering subsequent sleep.

Ann Intern Med. 2006;144:785-791.

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Sleep-related accidents represent up to 20% of all traffic accidents in industrial societies (1–3). Although sleepiness at the wheel is a well-known risk factor for traffic accidents, many people drive at night (4, 5) when alertness is at its lowest level. Connor and colleagues (3) have shown that driving between 2:00 a.m. and 5:00 a.m. increases the risk for traffic accidents by 5.6 times. Many people repeat this dangerous behavior because of economic rewards for professional drivers (6) or because of sociocultural factors (5, 7).

The age group that is most often involved in sleep-related accidents is 18 years to 25 years (1, 8). Nurses or physicians who often must stay awake for very long hours face the same risk (9, 10). Traffic accidents occurring between the workplace and home are a major cause of injury and death among workers (11, 12), and medical interns are particularly exposed (13).

Because of the conflicts between physiologic needs and social or professional activities (13–15), developing safe and affordable countermeasures to sleepiness at the wheel is a key issue in accident prevention. These countermeasures include sleeping (or napping) and the use of awakening agents, such as caffeine.

Caffeine is a widely used awakening substance. Adults in western societies are estimated to have an average all-source daily caffeine intake of about 200 mg to 300 mg (16). Within and above this dose range, caffeine increases alertness and reduces sleep propensity.

Some studies have tested the effects of caffeine on daytime driving in simulators by young sleep-deprived participants using caffeine pills, caffeinated beverages, or energy drinks (17, 18). Other studies have compared daytime naps with caffeine in driving simulators (19). However, no studies to date have tested the effects of coffee or napping on nighttime driving performances in a real-life environment.

A recent study comparing performances in real driving and driving simulators showed that sleepiness and performances are significantly more affected by sleep deprivation in a simulated environment than in the real world (20). This questions the validity of driving simulator studies, at least in the amplitude of effect of sleep deprivation or effect of countermeasures.

A real-life environment (such as a freeway rest area)

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Context

The effectiveness of coffee drinking and napping to maintain alertness during nighttime driving is unknown.

Contribution

Twelve healthy young men drove 125 miles on a straight highway in 4 sessions: 1 session during daylight and 3 sessions from 2:00 a.m. to 3:30 a.m. An hour before the nighttime driving sessions, participants drank decaffeinated coffee (placebo) or caffeinated coffee or took a 30-minute nap. The principal outcome was crossing the line between the lanes. The proportion of participants with no or 1 line crossing was 13%, 66%, and 75% after placebo, nap, and caffeinated coffee, respectively.

Implications

Drinking coffee or napping reduces impaired nighttime driving.

—The Editors

may also affect napping. A laboratory near a driving simulator after a night of sleep deprivation is an optimal place to fall asleep, even in the daytime. In real life, sleeping in a car at a highway rest area may not be so easy. On the other hand, the implications of real driving may reactivate the participants and could defer the effects of sleepiness at the wheel compared with the safe and boring environment of a driving simulator, which we have shown in a recent study (20).

Another very important point is the timing of the test: A combination of homeostatic and chronobiological factors explains the driving impairment. Epidemiologic studies show that sleep-related accidents occur most frequently in the middle of the night (3, 8). Testing countermeasures at that time is therefore crucial, combining extended wakefulness and chronobiological pressure. Other studies (19, 21) have tested the effect of caffeine, naps, or both on simulated driving, but the driving sessions were performed during the day or the early morning.

For these reasons, we designed a controlled, crossover study of real driving at night to study the effects of coffee or napping on nighttime driving performance.

METHODS**Participants**

We recruited 12 healthy men (mean age, 21.3 years [SD, 1.8]; range, 20 to 25 years). All participants provided written informed consent, and the local ethics committee (consultative committee for the protection of persons participating in biomedical research [CCPPRB Bordeaux A]) approved the study. All participants completed an Epworth Sleepiness Scale (ESS) (22), a Symptom Checklist 90 (SCL-90) (23), a Horne–Ostberg questionnaire (24), and a Basic Nordic Sleep Questionnaire (BNSQ) (25). We ex-

cluded participants who reported a sleep disorder, such as sleep apnea, insomnia (BNSQ score >3), or excessive daytime somnolence (ESS score >9).

We excluded participants with preexisting sleep disorders (diagnosed by clinical interview), organic disorders affecting sleep, or poor sleep hygiene and participants who were night or shift workers. Aside from the psychological profile evaluated by the SCL-90, we asked questions about substance abuse (caffeine, drug, or alcohol) during the clinical interview. We excluded participants who reported drug or alcohol abuse (more than 21 units per week) or who had an SCL-90 score greater than 59. All recruited participants were intermediate according to the Horne–Ostberg questionnaire.

Participants were not professional drivers, had had their driving license for at least 2 years, and drove between 10 000 km and 20 000 km per year.

Sleep Variables

Volunteers had to have normal usual sleep patterns as determined from an interview with a sleep specialist and 7 days' monitoring with actimeters (Actiwatch, Cambridge Neurotechnology, Cambridge, United Kingdom) (26) showing at least 85% mean sleep efficiency (27) over a week.

Study Design

This was a randomized, partly blinded, crossover study. All participants performed 4 driving sessions: 1 session from 6:00 p.m. to 7:30 p.m. in the daytime (reference condition) and 3 sessions from 2:00 a.m. to 3:30 a.m. (coffee, decaffeinated coffee, or nap condition), with at least 1 week between sessions. All participants started with the reference condition (Table). We randomly attributed the order of nocturnal driving sessions (nap, decaffeinated coffee, or coffee) to each participant in a balanced design by using a random permutations sequence.

Sleep Schedules and Sleep Recordings

We instructed the participants to maintain a regular sleep–wake schedule and monitored them by actimetry during the 3 days before each experimental session to verify the absence of sleep deprivation. We report only the last night's sleep duration in the Results section. We did not allow stimulants of any kind during the study. For the nocturnal testing periods, the participants came to the laboratory at 8:00 p.m. and were equipped with an ambulatory polysomnograph (Deltamed, Paris, France). Participants were not allowed to sleep before the driving sessions or the nap. We performed electroencephalography, electromyography, and electrooculography during the nap, the driving session, and the rest of the night after driving. All participants slept in a research room in the laboratory after the driving session. We calculated sleep latency from the time of lights out to the first epoch of stage 1 sleep. We calculated sleep efficiency by dividing the time in bed by the total sleep time from lights out to lights on.

Coffee and Placebo

We prepared coffee and placebo from 2 single packs of instant coffee (normal or decaffeinated) provided by Nestlé (Nestlé France, Noisiel, France). Coffee contained 4.25% of caffeine, and placebo (decaffeinated coffee) contained less than 0.3% of caffeine. Placebo and coffee were not distinguishable by taste or aspect.

Each participant drank 125 mL of instant coffee (about half a cup of coffee containing 200 mg of caffeine) or 125 mL of placebo (containing 15 mg of caffeine) 30 minutes before the nighttime driving session.

Napping

During the naps, the driver's seat was fully reclined, the participants were covered with a blanket, and an electrical heating system, which was installed in the car, maintained a constant temperature (19 °C). The car was parked in a quiet rest area and was guarded by the copilot so that no one disturbed the driver. The 30-minute nap started at 1:00 a.m., 1 hour before the driving session.

Driving Sessions

All participants drove 200 km (125 miles) on the same highway in separate lanes (100 km [62.5 miles] one way and 100 km [62.5 miles] the other way) for all conditions. The nighttime driving session started 30 minutes after ingestion of coffee or placebo or 30 minutes after awakening from the nap. Driving conditions were a straight highway on weekdays with usually light traffic conditions, in fair weather. All drivers were exposed to the same or very similar conditions. During a training session, participants were instructed to maintain a constant speed (130 kph [80 mph]), to drive in the center of the lane, and to not cross the painted lines separating the lanes except to pass a slower vehicle.

During the whole experiment, a professional driving instructor monitored the driving speed and noted the number of line crossings. The instructor was ready to take control of the car (which was equipped with dual controls) if needed. If a participant could no longer drive during a session, the participant was driven back to the rest area. The car used for the experiment was equipped with a video camera, which filmed and recorded the road, as described elsewhere (28, 29).

Sleepiness and Fatigue

Immediately before each driving session, we asked participants to rate their instantaneous fatigue ("Describe how fatigued you are now") on a 100-mm visual analogue scale. Scores ranged from 0 ("not at all tired") to 100 ("very tired"). Immediately after each driving session, participants were asked how sleepy they were during the session on a 100-mm visual analogue scale, with scores ranging from 0 ("not at all sleepy") to 100 ("very sleepy").

Outcome Measures

The main outcome was inappropriate line crossings identified from the video recordings. We selected this mea-

sure because epidemiologic findings show that 65% of sleep-related accidents occur after an inappropriate line crossing (30). Several studies have also shown that impaired daytime alertness induces lateral deviations during driving (31–33), and sleep-related accidents frequently occur with 1 car driving off the road and hitting an obstacle without reaction from the driver (8, 30). We recently published a study (28) showing that sleep restriction increased the risk for inappropriate line crossings in real daytime driving conditions by 8.5 times (95% CI, 3.5 to 20.5 times). We therefore selected inappropriate line crossings as our main outcome criterion to quantify the effect of coffee or napping on nocturnal driving impairment.

We recorded an inappropriate line crossing when the car crossed a lateral highway lane marker, as evidenced by video recording analysis. Exceptions were passing maneuvers or some other necessary driving actions as recorded by the driving instructor. We synchronized driving instructor and video recording timelines at the beginning of each session. We excluded deviations related to traffic interference to concentrate on line crossings related to driver status. The scorer of video recordings was blinded to the study period.

Secondary outcomes were participant classification (impaired or not impaired after the countermeasure) and reported sleepiness and fatigue. We classified participants as not impaired if they experienced only 1 or no line crossing during the nighttime driving session compared with the daytime driving session.

Statistical Analysis

We analyzed the results by using negative binomial regression in Stata, version 8.0 (Stata Corp., College Station, Texas), with the number of line crossings per driving session and per participant as the dependent variable and the conditions (coffee, placebo, or nap) as the determinants, clustered on participants. We compared participant classifications (impaired or not impaired) by using group proportion and nonparametric paired sign tests. We evaluated the effect of the condition on fatigue and sleepiness by analysis of variance (ANOVA) for repeated measurements. To correct for sphericity, we based all *P* values derived from ANOVA on Huynh–Feldt corrected degrees of freedom.

Results are reported as the total number of line crossings per session and per participant. We reported comparisons of line crossings among conditions as incidence rate ratios with 95% CIs and results for fatigue and sleepiness as means (SDs).

Role of the Funding Sources

This research was supported by a grant (PREDIT GO 3 [Programme de Recherche et d'Innovations dans les Transports Terrestres Groupe Opérationnel 3]) from the French Ministry of Research and Laboratoire d'Accidentologie et de Bio Mécanique (Peugeot Société Anonyme Peugeot Citroën and Renault). The funding

sources did not have a role in the design, conduct, or reporting of the study or in the decision to submit the manuscript for publication.

RESULTS

All participants completed the study and all driving sessions. No protocol deviations occurred.

Line Crossings

The Table shows the numbers of line crossings per participant and per condition. The incidence rate ratios of a line crossing in the placebo condition were 3.7 (95% CI, 1.2 to 11.0; $P = 0.001$) compared with the coffee condition and 2.9 (CI, 1.7 to 5.1; $P = 0.021$) compared with the nap condition (main outcome measure).

In the daytime condition, 10 participants had no line crossings and 2 participants had 1 line crossing. In the coffee condition, 9 of the 12 participants were considered to be nonimpaired: Seven had no line crossings, and 2 had 1 line crossing. In the nap condition, 8 of 12 participants were not impaired: Six had no line crossings, and 2 had 1 line crossing. In the placebo condition, only 3 participants were not impaired: Two had no line crossings, and 1 had 1 line crossing. The difference in the proportion of unimpaired participants between the coffee (75%) and nap (66%) conditions was not significant ($P = 0.66$). There were significantly fewer nonimpaired participants (13%) in the placebo session than in the coffee ($P = 0.014$) or nap ($P = 0.041$) session.

Self-Perception of Fatigue and Sleepiness

Fatigue measured by a visual analogue scale before driving increased significantly between the daytime and nighttime conditions (ANOVA, $F = 3.8$; $P = 0.021$). The 3 nighttime conditions did not differ (Figure 1).

Sleepiness at the wheel measured by a visual analogue scale after driving increased significantly between daytime and nighttime conditions (ANOVA, $F = 6.1$; $P = 0.007$). Sleepiness at the wheel did not differ after coffee or nap

but was significantly worse after placebo ($P = 0.004$ vs. coffee; $P = 0.034$ vs. nap) (Figure 2).

Sleep Variables

Participants slept for a mean of 432 minutes (SD, 31) (sleep efficiency, 90% [SD, 4%]) during the night before the daytime driving session. Participants slept for a mean of 447 minutes (SD, 40) (sleep efficiency, 92% [SD, 7%]) on the night before the placebo session, a mean of 437 minutes (SD, 34) (sleep efficiency, 92% [SD, 5%]) on the night before the coffee session, and a mean of 426 minutes (SD, 33) (sleep efficiency, 91% [SD, 6%]) on the night before the nap session. Sleep duration or sleep efficiency of the placebo session did not significantly differ from those of the coffee and nap sessions (Friedman chi-square test, 0.028 [$P = 0.999$] and 5.727 [$P = 0.126$], respectively).

During the nap, participants slept in the car for a mean of 23 minutes (SD, 4). Back in the laboratory after driving, sleep latencies slightly increased with coffee (2.5 minutes [SD, 1.7]; ANOVA, $F = 5.046$; $P = 0.046$) or nap (3.2 minutes [SD, 2.9]; ANOVA, $F = 6.89$; $P = 0.024$) compared with placebo (1.7 minutes [SD, 1.6]). Sleep efficiency was not modified by coffee (96.3% [SD, 1.4%]) or nap (94.5% [SD, 4.6%]) compared with placebo (95.5% [SD, 2.6%]).

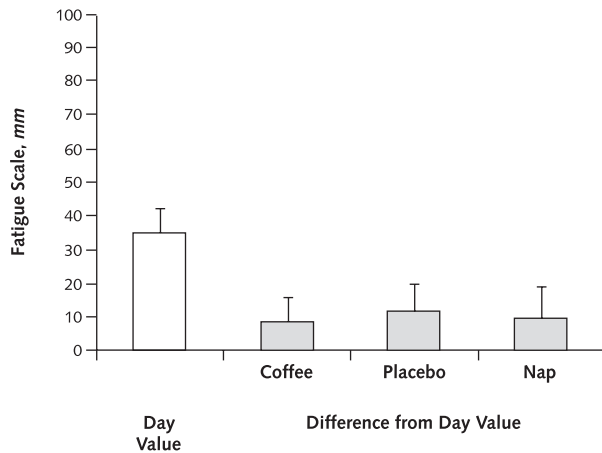
DISCUSSION

Our study was a randomized, double-blind, crossover clinical trial of the effect of caffeinated versus decaffeinated coffee on real nighttime driving performance on an open highway, with 2 open sessions added (1 session in the afternoon to obtain a reference for “normal” driving and the other session to test napping). We could not devise a “placebo nap,” but the scorers of the video recordings of the different nighttime driving sessions were blinded to the condition (coffee, decaffeinated coffee, or nap). We also confirmed that the participants were effectively nap-adherent and that they slept during the nap by using the poly-

Table. Line Crossings per Participant and Driving Session

Participant	Order of Sessions	Line Crossings, <i>n</i>			
		Daytime Condition	Coffee Condition	Placebo Condition	Nap Condition
1	Daytime, nap, coffee, placebo	0	1	11	6
2	Daytime, nap, placebo, coffee	1	3	2	1
3	Daytime, nap, coffee, placebo	0	0	3	3
4	Daytime, nap, placebo, coffee	1	0	13	6
5	Daytime, coffee, placebo, nap	0	1	2	1
6	Daytime, coffee, placebo, nap	0	0	2	0
7	Daytime, coffee, nap, placebo	0	13	17	8
8	Daytime, coffee, nap, placebo	0	2	0	0
9	Daytime, placebo, nap, coffee	0	0	11	0
10	Daytime, placebo, coffee, nap	0	0	11	0
11	Daytime, placebo, coffee, nap	0	0	1	0
12	Daytime, placebo, nap, coffee	0	0	0	0
Total		2	20	73	25

Figure 1. Self-evaluation of fatigue before the driving sessions.



The score was based on a 100-mm visual analogue scale with scores ranging from 0 (“not at all tired”) to 100 (“very tired”). Values for the daytime driving session are absolute values (95% CI), and values for the 3 test periods are mean individual differences from the daytime period (95% CI). Greater values indicate worse results. All 3 nighttime conditions (coffee, placebo, or nap) were worse than the daytime condition ($P < 0.05$ [analysis of variance]) but did not differ from each other.

somnographic recording. We chose to compare a 30-minute nap with 200 mg of caffeine because we wanted to match the usual break duration that we observed in a previous study (34).

We found a statistically significant increase in line crossings during nighttime driving compared with a daytime driving session of the same duration and distance. This confirms previous findings (28). Extended time awake and sleepiness at the wheel are associated with lateral deviations, which are a frequent cause of sleep-related accidents (8, 30).

Of interest, as we showed in a previous paper (28), some participants were very severely affected by sleepiness at the wheel during the placebo condition while others tolerated nocturnal driving well. Because we carefully controlled the sleep duration before each driving session, this interindividual variability cannot be explained by a previous sleep deprivation. Our results are consistent with those of Leproult and colleagues (35) and Van Dongen and colleagues (36), which clearly show a great interindividual variability in vulnerability to sleep loss. Some differential expression of alerting systems may explain these differences and why some participants respond more to caffeine (which boosts these systems) than others.

As well as confirming that healthy participants can fall asleep at a highway rest area if the sleep pressure is strong enough, our study shows that both coffee and napping statistically significantly reduced inappropriate line crossings during nighttime driving. These results confirm those of previous studies performed in daytime driving simula-

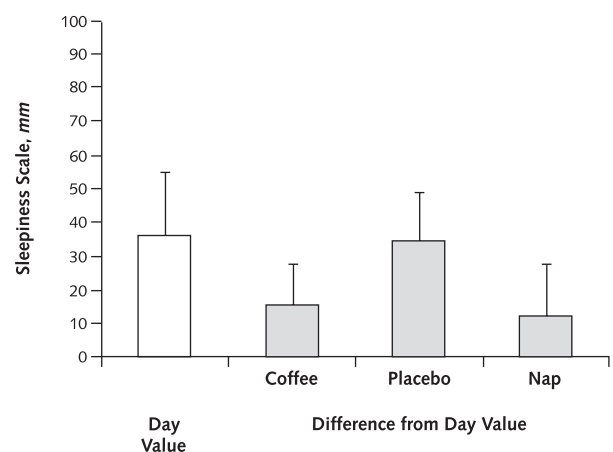
tors. Coffee and napping affect not only line crossings but also sleepiness at the wheel. If line crossings and accident rates indeed have a linear risk relationship, as suggested by the relationship between blood alcohol concentrations and line crossings on one hand and risk for accident on the other (29, 37), coffee and naps could reduce nighttime accidents related to sleepiness by 3 to 4 times (37).

Although caffeine and naps statistically significantly reduced sleepiness compared with placebo, we did not observe a statistically significant difference in fatigue. This could be explained by the fact that coffee and a short nap mainly act on sleep-wake systems and not on central nervous systems involved in fatigue.

Coffee and napping may not have exactly the same mode of action. Sleepiness in the middle of the night is the result of homeostatic pressure from the duration of time awake and of chronobiological pressure from being awake at the wrong time of day. Napping will decrease the homeostatic pressure but not necessarily the chronobiological pressure. Caffeine’s alerting properties will act indifferently on both components and may restore performance more efficiently. While we had limited power to examine sleep quality after nighttime driving, our results indicate that neither coffee nor napping seemed to impair subsequent sleep in a clinically significant manner.

Of interest, some participants respond very well to caffeine but do not improve greatly after a nap, while others benefit more from a short sleep than from caffeine. Both countermeasures should be proposed and promoted

Figure 2. Self-evaluation of sleepiness at the wheel during the driving sessions.



The score was based on a 100-mm visual analogue scale with scores ranging from 0 (“not at all sleepy”) to 100 (“very sleepy”). Values for the daytime driving session are absolute values (95% CI), and values for the 3 test periods are mean individual differences from the daytime period (95% CI). Greater values indicate worse results. All 3 nighttime conditions (coffee, placebo, or nap) were worse than the daytime condition ($P < 0.05$ [analysis of variance]). Sleepiness was worse during the placebo condition than in either countermeasure condition (caffeine, $P < 0.004$; nap, $P < 0.034$).

to decrease the risk for accidents at night. Both countermeasures are about equally efficient in reducing line crossings, and we have no preference of one over the other, although it could be argued that coffee seems slightly more effective. Participants should choose according to their own physiologic response. Further studies are needed to define optimal doses of caffeine and duration of sleep according to interindividual vulnerability to sleep loss, sensitivity to the countermeasures, or both.

We did not test the combination of caffeine and napping or the dose–response (or duration–response) curves for caffeine or napping. We also have not tested the effects of caffeine or naps in drivers with chronic sleep deprivation or in patients with sleep disorders (for example, obstructive sleep apnea syndrome). It will also be interesting to test the effects of coffee in participants who routinely consume high amounts of caffeinated beverages. This group of participants may not respond as well to caffeine and should be instructed to choose naps or a combination of caffeine and naps as a countermeasure to sleepiness at the wheel.

These interventions should be studied further to examine whether the effects also occur in participants who differ from the participants in our study (young, healthy, well-rested men with modest baseline coffee intake). The real-life effects of caffeine and napping before nighttime driving on actual accident rates also warrant verification.

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Acknowledgments: The authors thank Autoroutes du Sud de la France for allowing the use of their highways for the research, Nestlé for providing the coffee and decaffeinated coffee, GIE RE PSA (Groupement d'Intérêt Économique Recherche Peugeot Société Anonyme) Peugeot Citroën Renault for helping in the administrative coordination of the project, and T. Spector and C. Gilbert for managing the Groupe Opérationnel 3 (GO 3) (PREDIT [Programme de Recherche et d'Innovations dans les Transports Terrestres]).

Potential Financial Conflicts of Interest: None disclosed.

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Please submit photographs or questions to Christine Laine, MD, MPH, Senior Deputy Editor, *Annals of Internal Medicine*, 190 N. Independence Mall West, Philadelphia, PA 19106-1572, claine@acponline.org. We look forward to receiving your photographs.

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