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RESEARCH ARTICLE

# Ignition Interlock Laws: Effects on Fatal Motor Vehicle Crashes, 1982–2013

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**Introduction:** Alcohol-involved motor vehicle crashes are a major cause of preventable mortality in the U.S., leading to more than 10,000 fatalities in 2013. Ignition interlocks, or alcohol-sensing devices connected to a vehicle's ignition to prevent it from starting if a driver has a predetermined blood alcohol content (BAC) level, are a promising avenue for preventing alcohol-involved driving. This study sought to assess the effects of laws requiring ignition interlocks for some or all drunk driving offenders on alcohol-involved fatal crashes.

**Methods:** A multilevel modeling approach assessed the effects of state interlock laws on alcohol-involved fatal crashes in the U.S. from 1982 to 2013. Monthly data on alcohol-involved crashes in each of the 50 states was collected in 2014 from the National Highway Traffic Safety Administration Fatality Analysis Reporting System. Random-intercept models accounted for between-state variation in alcohol-involved fatal crash rates and autocorrelation of within-state crash rates over time. Analysis was conducted in 2015.

**Results:** State laws requiring interlocks for all drunk driving offenders were associated with a 7% decrease in the rate of BAC $>0.08$ fatal crashes and an 8% decrease in the rate of BAC $\geq 0.15$ fatal crashes, translating into an estimated 1,250 prevented BAC $>0.08$ fatal crashes. Laws requiring interlocks for segments of high-risk drunk driving offenders, such as repeat offenders, may reduce alcohol-involved fatal crashes after 2 years of implementation.

**Conclusions:** Ignition interlock laws reduce alcohol-involved fatal crashes. Increasing the spread of interlock laws that are mandatory for all offenders would have significant public health benefit.
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## INTRODUCTION

Alcohol-involved fatal motor vehicle crashes are a major cause of preventable mortality in the U.S. Thirty-one percent ($n$=10,076) of the 33,804 motor vehicle crash fatalities in 2013 involved at least one driver with blood alcohol content (BAC) of $\geq 0.08$ g/dL.[1] Despite declining rates of motor vehicle crashes overall and alcohol-involved crashes specifically over the past 4 decades[2,3]—attributable in part to enactment/enforcement of state laws to increase driving safety generally (e.g., seatbelt laws)[4] and to reduce alcohol-involved driving (e.g., BAC 0.08 laws)[5]—rates of alcohol-involved fatal crashes in the U.S. remain high. Developing interventions to further reduce rates of driving while under the influence (DUI) and resultant fatal crashes is a public health priority.

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As of 2016, all 50 states and DC prohibit motorists from driving with a BAC of ≥0.08 g/dL and have "zero tolerance" laws prohibiting those aged ≤21 years from driving with a BAC of ≥0.02.[6,7] These policies' effectiveness is limited owing to enforcement challenges.[8] License suspension/revocation is the primary enforcement mechanism for violation of DUI laws. However, more than half of people subject to DUI-related driving prohibitions drive despite the fact that their license is suspended/revoked,[9] and critics argue that the practice of suspending/revoking driving privileges following DUI conviction interferes with individuals' ability to work and carry out other activities that require driving.[10]

Ignition interlocks are a promising avenue for addressing some of these enforcement challenges and directly preventing alcohol-involved driving. An ignition interlock is an alcohol-sensing device, connected to the ignition of a vehicle, which detects alcohol in the driver's breath. If alcohol in excess of a preset limit is detected by the sensor, the vehicle will not start.[11] Many interlocks also require a rolling retest for the vehicle to continue operating.[11]

All 50 states have some level of ignition interlock law. Broadly speaking, these laws fall into three categories. "Permissive" interlock laws allow judges or other sentencing authorities, at their discretion, to require individuals convicted of DUI offense to use an interlock. "Partial" laws mandate interlock use for specific categories of offenders, such as repeat DUI offenders. "Mandatory/all" laws require all individuals convicted of a DUI offense to use an interlock in order to drive legally. As of March 2016, two states have permissive interlock laws, 22 states have partial interlock laws, and 26 states have mandatory/all interlock laws. Adoption of interlock laws was partly prompted by enactment of a 2000 federal law that provided financial incentives for states to enact interlock laws.[12]

Research regarding ignition interlocks is limited but growing. When installed, interlocks can reduce DUI recidivism.[13–19] Less is known about the effects of interlocks on alcohol-involved crashes, particularly fatal crashes.[20–22] One prior 50-state study,[23] which used a difference-in-difference in design, found that mandatory/all interlock laws resulted in a 15% reduction in alcohol-involved crash deaths. However, this study did not examine the effects of partial interlock laws or account for the fact that many states in the study's control group, defined as including states without mandatory/all interlock laws, had partial interlock laws in effect during the study period.

Although partial interlock laws cover only a segment of all DUI offenders, these laws target groups at high risk of alcohol-involved fatal crashes, including repeat DUI and high BAC offenders.[24–26] Unlike permissive laws, which leave interlock requirements to the discretion of sentencing officials and are therefore unlikely to be uniformly implemented or have measurable effects on overall crash rates, partial laws make ignition interlocks mandatory for these high-risk offenders. Partial interlock laws have been shown in prior studies to reduce DUI recidivism[15] and have the potential to reduce alcohol-involved crash fatalities. To date, however, the effects of partial interlock laws on alcohol-involved fatal crashes, and the effects of mandatory/all interlock laws above and beyond partial laws, are unknown.

A 50-state multilevel analysis was conducted to assess the impact of partial and mandatory/all ignition interlock laws on alcohol-involved fatal crashes in the U.S. Hypotheses were that partial interlock laws would be associated with lower rates of alcohol-involved fatal crashes, and that mandatory/all interlock laws would be associated with larger reductions in rates of alcohol-involved fatal crashes than partial interlock laws.

## METHODS

To estimate the effects of partial and mandatory/all ignition interlock laws on fatal alcohol-involved crashes, a multilevel modeling approach was used to assess changes in pre/post interlock law rates of alcohol-involved fatal crashes. Given that 43 states enacted a partial or mandatory/all interlock law at various timepoints during the 1982–2013 study period, this multilevel modeling analytic approach is better suited to the nature of the data than other approaches, such as difference-in-difference analysis, synthetic control approaches, or meta-analysis of the results of 50 individual, state-specific models. Though these well-established approaches are often appropriate for state policy evaluations, they all require identification of a control group of states with similar demographic composition, comparable pre-law trends in the outcome of interest, and without policy implementation in the post-law period. Given that only seven states did not implement a partial or mandatory/all interlock law during the study period, and that these states tended to be rural states with relatively small populations (Indiana, Kentucky, Michigan, Montana, North Dakota, Rhode Island, and South Dakota), identification of an uncontaminated control group with similar demographics and trends in alcohol-involved fatal crashes was not feasible.

### Data Sample

The analytic data set was constructed at the state–month level, with 384 month-level observations per state. Interlock law data were generated by original legal research conducted by the public health lawyers and a JD/MPH student on the study team (JV, LR, and JS). To identify and categorize interlock laws in each state, statutes and regulations, obtained through Westlaw® and state law databases, were reviewed to identify the current category (permissive, partial, mandatory/all) and effective date of the current interlock laws in each state. Additionally, each relevant state law's legislative history was reviewed to determine the effective date of each state's initial interlock law and how and when the state's interlock laws changed over the study period.

A detailed description of the legal research process used is available elsewhere.[27]

Data on the number of alcohol-involved fatal crashes per month in the 50 U.S. states from 1982 to 2013 were obtained in 2014 from the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (FARS).[28] FARS contains data on all fatal traffic crashes occurring on public roads in the U.S. and reports the BAC of drivers involved in such crashes. Driver BAC is not measured for every fatal crash, and FARS uses multiple imputation to estimate alcohol-involved crashes when BAC data are not reported. Covariate data were obtained from the U.S. Census Bureau, the Insurance Institute for Highway Safety, and the National Highway Traffic Safety Administration.

### Measures

Partial and mandatory/all interlock laws were measured as dichotomous variables that "turned on" during the month/year they went into effect in a given state. When states transitioned from a partial to a mandatory/all interlock law, the partial interlock law variable was coded as "1" up to the point that the mandatory/all interlock law became effective. At that point, the partial interlock law variable was coded as "0" and the mandatory/all variable was coded as "1" for the remainder of the study period.

The dependent variable of interest was alcohol-involved fatal crash rates, defined as the rate of alcohol-involved motor vehicle crashes in which one or more people were killed per the number of licensed drivers in a given state. State laws prohibit all drivers from operating a vehicle with BAC $\geq$0.08 but some partial interlock laws applied only to high BAC offenders. Nearly all states during the 32-year study period that had partial interlock laws for high BAC offenders used BAC $>$0.15 to define this group. Two measures of alcohol-involved fatal crashes were created: crashes in which FARS indicates that a driver had a BAC $\geq$0.08 and crashes in which a driver had a BAC $\geq$0.15.

Covariates included in statistical models were time-varying policy variables that prior research suggests influence alcohol-involved fatal crashes, including dichotomous indicators of the month in which states enacted BAC 0.08 laws,[29] zero tolerance laws,[30] and primary seatbelt enforcement laws.[31] Though shown to reduce alcohol-involved fatal crashes,[32,33] minimum age 21 years drinking laws were not included as a model covariate because these laws were in effect in all 50 states for the majority of the study period. To account for the unmeasured social forces underlying societal trends in alcohol-involved fatal crashes, the national rate of alcohol-involved fatal crashes served as a generalized control in all models. To further control for the general downward trend in alcohol-involved fatal crashes over the study period, a linear time trend measured as a continuous year variable was included.

Demographic covariates known to be associated with alcohol-involved driving, including poverty, alcohol consumption, and proportion of young male drivers,[34–36] changed very little within states over the study period. As use of state random intercepts in statistical models already accounted for underlying between-state differences in alcohol-involved fatal crash rates, these largely time-invariant demographic factors were excluded from analytic models.

### Statistical Analysis

Negative binomial regression using random effects generalized linear models, with a random intercept for each state, was used to assess the effects of interlock laws on alcohol-involved fatal crash rates. Random-intercept models allow for variation in underlying alcohol-involved fatal crash rates across states while also accounting for autocorrelation of within-state crash rates over time. All models included licensed drivers as a population offset term, making results interpretable as incidence rate ratios. In the model building process, alternative working correlation structures were considered. Models using exchangeable correlation structure had better fit than alternative models using autoregressive error structure.

Two primary statistical models were calculated. Model 1 included interlock law variables, the national rate of alcohol-involved fatal crashes generalized control, and the linear time trend. Model 2 added time-varying law variables: BAC 0.08, zero tolerance, and primary seatbelt enforcement laws. Both models were estimated for BAC $\geq$0.08 and BAC $\geq$0.15 fatal crashes. By including measures of both partial and mandatory/all interlock laws, this modeling strategy allowed the authors to test for a dose–response relationship between the strength of interlock laws and alcohol-involved fatal crashes. Model results were translated into number of fatal crashes prevented by applying the percent change in alcohol-involved fatal crash rates indicated by the incidence rate ratio to the population of licensed drivers exposed to the laws.

Three sensitivity analyses were conducted, all using Model 2. The effects of interlock laws may be delayed by time needed to scale up implementation; Model 2 was therefore repeated using 12-, 24-, and 36-month lagged interlock law indicators (e.g., a law enacted in January 2005 was coded as going into effect in January 2006 [12-month lag], January 2007 [24-month lag], or January 2008 [36-month lag]). Because the principal analyses use multiple imputed BAC data from the FARS database, Model 2 was repeated using the complete, non-imputed data on single-vehicle nighttime (9:00PM–5:59AM) fatal crashes, an established proxy for alcohol-involved fatal crashes.[37] Finally, a placebo test was conducted to assess the effects of interlock laws on non–alcohol involved fatal crashes. All analyses were conducted using Stata, version 14, in 2015. This study was approved by the IRB at the Johns Hopkins Bloomberg School of Public Health.

## RESULTS

From 1982 to 2013, partial interlock laws were enacted by 36 states. Twenty-one states, 13 of which already had partial interlock laws in effect, enacted mandatory/all laws during the study period (Table 1). The majority of mandatory/all interlock laws were implemented in the latter part of the study period, with 16 of 21 states implementing such laws in 2005 or later.

In Model 1 (Table 2), mandatory/all laws were associated with 9% and 10% declines in BAC $\geq$0.08 and BAC $\geq$0.15 fatal crash rates ($p<0.001$). Partial interlock laws were associated with a 2% and 3% declines in BAC $\geq$0.08 ($p=0.025$) and BAC $\geq$0.15 ($p<0.001$) crash rates. In Model 2 (Table 3), mandatory/all interlock laws were associated with 7% and 8% reductions in BAC $\geq$0.08 and BAC $\geq$0.15 fatal crash rates ($p<0.001$). In

**Table 1.** Ignition Interlock Laws in the U.S., 1982–2013

| State | Partial interlock law | Mandatory/all interlock law |
|---|---|---|
| | Effective month and year | Effective month and year |
| Alabama | September 2011 | – |
| Alaska | January 2005 | January 2009 |
| Arizona | August 1999 | September 2007 |
| Arkansas | – | April 2009 |
| California | July 1993 | – |
| Colorado | July 1999 | August 2012 |
| Connecticut | October 2003 | January 2012 |
| Delaware | July 2002 | – |
| Florida | July 2002 | – |
| Georgia | July 1993 | – |
| Hawaii | – | July 2010 |
| Idaho | October 2000 | – |
| Illinois | August 2001 | January 2009 |
| Indiana | – | – |
| Iowa | – | July 1995 |
| Kansas | July 1993 | July 2011 |
| Kentucky | – | – |
| Louisiana | August 1997 | – |
| Maine | September 2008 | December 2013 |
| Maryland | September 2002 | – |
| Massachusetts | January 2006 | – |
| Michigan | – | – |
| Minnesota | July 2011 | – |
| Mississippi | September 2000 | – |
| Missouri | January 1996 | – |
| Montana | – | – |
| Nebraska | – | January 2009 |
| Nevada | October 2005 | – |
| New Hampshire | January 2013 | – |
| New Jersey | January 2010 | – |
| New Mexico | January 2003 | April 2003 |
| New York | September 2003 | December 2009 |
| North Carolina | July 2000 | – |
| North Dakota | – | – |
| Ohio | September 2008 | – |
| Oklahoma | – | July 1995 |
| Oregon | – | July 1993 |
| Pennsylvania | September 2000 | – |
| Rhode Island | – | – |
| South Carolina | July 2007 | – |
| South Dakota | – | – |
| Tennessee | October 2002 | July 2013 |
| Texas | September 1995 | – |
| Utah | May 2000 | July 2009 |
| Vermont | – | July 2011 |
| Virginia | July 2004 | July 2012 |
| Washington | – | January 1999[a] |
| West Virginia | July 2005 | August 2008 |
| Wisconsin | September 2001 | – |
| Wyoming | July 2009 | – |

[a]Washington's mandatory/all interlock law initially became effective January 1999. It was then repealed on May 14, 1999, and then reinstated effective June 10, 2004.

this model, partial interlock laws had no effect on alcohol-involved fatal crashes.

Model results for the effects of mandatory/all interlock laws on alcohol-involved fatal crash rates were insensitive to the addition of 12-, 24-, and 36-month lags to account for possible implementation scale-up (Appendix Tables 1 and 2, available online). Lagged models suggest possible scale-up effects for partial interlock laws, with these laws showing significant protective effects on both BAC $\geq$0.08 and BAC $\geq$0.15 fatal crash rates when 24-month or 36-month lags were added. Estimates of the effects of interlock laws on single vehicle nighttime crashes were nearly identical to estimates of the laws' effects on BAC $\geq$0.08 and BAC $\geq$0.15 crashes (Appendix Tables 3 and 4, available online). The placebo test showed no effects of either mandatory/all or partial interlock laws on non–alcohol involved crashes (Appendix Table 5, available online).

## DISCUSSION

This study suggests clear protective effects of mandatory/all interlock laws on alcohol-involved fatal crashes, which were associated with an estimated 7% reduction in BAC $\geq$0.08 and 8% reduction in BAC $\geq$0.15 fatal crashes. This translates into approximately 1,250 BAC $\geq$0.08 fatal crashes prevented in states that implemented such laws between 1982 and 2013.

When no delay in implementation was assumed, the authors found no effects of partial interlock laws on alcohol-involved fatal crashes. However, partial

**Table 2.** Effects of Interlock Laws on BAC≥0.08 and BAC≥0.15 Fatal Motor Vehicle Crashes, 1982–2013

| | Alcohol-involved fatal motor vehicle crashes | | | |
|---|---|---|---|---|
| | BAC≥0.08 fatal crashes[a] | | BAC≥0.15 fatal crashes[b] | |
| **Independent variables and covariates** | **IRR (95% CI)** | ***p*-value** | **IRR (95% CI)** | ***p*-value** |
| Ignition interlock laws | | | | |
| Mandatory/all | 0.91 (0.89, 0.94) | **<0.001** | 0.90 (0.88, 0.93) | **<0.001** |
| Partial | 0.98 (0.97, 0.99) | **0.035** | 0.97 (0.95, 0.98) | **<0.001** |
| National rate of alcohol-involved fatal crashes | 3.62 (3.49, 3.74) | **<0.001** | 8.68 (8.07, 9.33) | **<0.001** |
| Year (linear time trend) | 0.993 (0.992, 0.994) | **<0.001** | 0.995 (0.994, 0.996) | **<0.001** |

*Note:* Boldface indicates statistical significance ($p<0.05$).
[a]Motor vehicle crashes resulting in one or more fatalities where a driver involved in the crash had BAC≥0.08 g/dL.
[b]Motor vehicle crashes resulting in one or more fatalities where a driver involved in the crash had BAC≥0.15 g/dL.
BAC blood alcohol content; IRR, incident rate ratio.

laws showed beneficial effects on alcohol-involved fatal crashes beginning 24 months after policy enactment. This finding may be explained by the fact that implementation delays, such as delays related to the need for states to contract with interlock vendors, are more likely to occur when a state first requires interlocks for some DUI offenders. Given that 13 of 21 states with mandatory/all interlock laws had a partial interlock law previously in effect, delays may have been, on average, more relevant for implementation of partial versus mandatory/all interlock laws. The dose–response relationship identified here, with mandatory/all interlock laws having a larger effect than partial interlock laws, increases the likelihood that the observed relationship between interlock laws and alcohol-involved fatal crashes is causal.

Study findings regarding the protective effects of mandatory/all interlock laws are qualitatively similar to the results of the prior 50-state interlock law study by Kaufman et al.,[23] though several methodologic differences should be considered when comparing results. Kaufman and colleagues employed a difference-in-difference approach, using year-level data, to assess the effects of mandatory/all interlock laws on fatalities from crashes where a driver had a BAC >0. The present study assessed both partial and mandatory/all interlock laws and used precise implementation months for the laws. The primary outcomes were BAC ≥0.08 and BAC ≥0.15 fatal crashes, measured at the crash level rather than individual fatality level, which could skew results because of outlying multiple-fatality incidents. As there was no strong theoretic reason to expect delays in implementation of interlock laws, especially mandatory/all laws, the effects of interlock laws were primarily modeled as beginning in the month that a given law went into effect. Although Kaufman and colleagues found no effects of mandatory/all laws until 3 years after implementation, this study found immediate protective effects of such laws, a finding strengthened by the fact that there

**Table 3.** Effects of Interlock and Other Laws on BAC≥0.08 and BAC≥0.15 Fatal Motor Vehicle Crashes, 1982–2013

| | Alcohol-involved fatal motor vehicle crashes | | | |
|---|---|---|---|---|
| | BAC≥0.08 fatal crashes[a] | | BAC≥0.15 fatal crashes[b] | |
| **Independent variables and covariates** | **IRR (95% CI)** | ***p*-value** | **IRR (95% CI)** | ***p*-value** |
| Ignition interlock laws | | | | |
| Mandatory/all | 0.93 (0.91, 0.96) | **<0.001** | 0.92 (0.90, 0.95) | **<0.001** |
| Partial | 1.01 (0.99, 1.03) | 0.105 | 1.00 (0.98, 1.02) | 0.832 |
| National rate of alcohol-involved fatal crashes | 3.69 (3.56, 3.81) | **<0.001** | 9.00 (8.86, 9.68) | **<0.001** |
| BAC 0.08 law | 0.94 (0.93, 0.95) | **<0.001** | 0.92 (0.91, 0.94) | **<0.001** |
| Zero tolerance law[c] | 0.98 (0.97, 0.99) | **0.018** | 0.98 (0.96, 0.99) | **0.009** |
| Primary seatbelt enforcement law | 0.90 (0.88, 0.91) | **<0.001** | 0.89 (0.87, 0.90) | **<0.001** |
| Year (linear time trend) | 0.998 (0.997, 1.00) | 0.138 | 1.00 (1.001, 1.003) | **0.033** |

*Note:* Boldface indicates statistical significance ($p<0.05$).
[a]Motor vehicle crashes resulting in one or more fatalities where a driver involved in the crash had BAC≥0.08 g/dL.
[b]Motor vehicle crashes resulting in one or more fatalities where a driver involved in the crash had BAC≥0.15 g/dL.
[c]Laws prohibiting those aged <21 years from driving with a BAC ≥0.02 g/dL.
BAC, blood alcohol content; IRR, incident rate ratio.

were no observed effects of such laws on non–alcohol involved crashes, as would be expected if this result were due to trends in motor vehicle crashes unrelated to interlock laws. Sensitivity analyses did, however, suggest the possibility of delayed implementation effects for partial interlock laws.

Further, the states identified as having mandatory/all interlock laws differed slightly in the two studies. Using information compiled by Trust for America's Health,[38] Kaufman et al.[23] identified 18 states as having mandatory/all laws as of 2013. The present study identified 21 states. This discrepancy seems to be due to the fact that Iowa, Oklahoma, Vermont, and West Virginia, considered as having mandatory/all laws in this study but not by Trust for America's Health, have policies in which a driver can choose to either install an interlock or have their license suspended, as opposed to simply being required to use an interlock with no option of suspension. Because use of an interlock is the only way an individual subject to such a law can legally drive, these are, in practice, comparable to mandatory/all laws. Although it is possible that some DUI offenders in states with a license suspension/interlock option might choose suspension and drive without a license, driving without a license or an interlock remains possible (albeit illegal) in all states with an interlock law. Future research on rates of interlock installation among DUI offenders in states with versus without the license/suspension option is needed to clarify this issue. Re-coding these states as not having mandatory/all laws had no substantive effect on the significance of the results for mandatory/all laws, though the magnitude of effect was somewhat greater: For Model 2, the incidence rate ratio for mandatory/all laws was 0.83 (95% CI=0.81, 0.86). Trust for America's Health identified Louisiana as having a mandatory/all interlock law, and this study did not. Coding Louisiana as having a mandatory/all law had no effect on results (results not shown).

Research on existing interlock laws shows compliance problems: A 2002 study of an interlock policy in California found that only 22% of offenders subject to an interlock order installed an interlock,[39] and a more recent 2009 study of New Mexico's interlock law showed a 50% installation rate.[40] Lack of data systems needed to monitor interlock installation and use appears to be a major implementation barrier.[11] Cost of purchasing and installing an interlock device is typically borne by the individual subject to the interlock mandate, which likely decreases compliance with the law.[11] Future research should assess strategies to improve implementation of interlock laws, for example, financial assistance programs, electronic monitoring systems, and the development of cheaper/more user-friendly interlock devices.

### Limitations

The FARS data use multiple imputation to address missing data for alcohol-involved crashes. Although imputation could introduce measurement error, nearly identical effects of interlock laws on non-imputed measures of single vehicle nighttime crashes were observed. The multilevel modeling approach incorporated time-varying indicators of key road safety laws known to influence alcohol-involved crashes but may have failed to account for other time-varying confounders. Assessment of specific interlock law provisions, such as supervision and monitoring requirements and differences in implementation and enforcement across state interlock laws, was outside the scope of this study and should be considered by future research.

## CONCLUSIONS

Laws mandating interlock use for all offenders are more effective at reducing alcohol-involved fatal crashes than laws requiring interlocks for segments of high-risk offenders. Enactment of mandatory/all interlock laws in states that currently have partial and permissive laws is a public health priority.

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## SUPPLEMENTAL MATERIAL

Supplemental materials associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.amepre.2016.10.043.

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