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Review article

Low blood alcohol concentrations and driving impairment

A review of experimental studies and international legislation

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Summary. While noting that there is no international scientific or legislative uniformity in blood alcohol concentration (BAC) levels admissible for driving motor vehicles, the authors analyse problems concerning the effects of low levels of ethyl alcohol on driving ability.

A summary of the international literature on this subject reveals:
– the existence of contrasting assumptions, with scientific evidence clearly demonstrating altered psychomotor functions;
– the need to adopt sufficiently complex psychometric tests to reveal the effects of low BACs;
– the need to improve standardization of experimental studies on man-machine interaction;
– the need to investigate the following areas: tolerance to alcohol; low BACs with inexperienced, infrequent drinkers and chronic, heavy drinkers; hangover effects; alcohol-gender-age interactions, and specific effects on young drivers; alcohol-drug combinations.

The analysis of legislation and enforcement policies also reveals the need for:
– re-evaluation of the international legal BAC threshold and standardization of procedures for ascertaining the degree of driving disability;
– further scientific research to compare and evaluate selected legislative initiatives currently in place in most states; to identify the best strategies and procedures to detect and arrest impaired drivers; to determine the optimum random testing rate to maximize deterrent effects in the workplace at minimal cost; to design innovative and comprehensive approaches to rehabilitation programs needed for subgroups of offenders and of workers; to study the effectiveness of new legislations and policies.

Key words: Ethyl alcohol – Low doses – Traffic safety – Psychomotor performance – Driving ability

Zusammenfassung. In der Erkenntnis, daß es keine internationale wissenschaftliche oder gesetzliche Einheitlichkeit im Hinblick auf die zulässigen Blutalkoholkonzentrationen beim Fahren von Kraftfahrzeugen gibt, analysieren die Autoren die Probleme, welche die Auswirkungen niedriger Alkoholkonzentrationen auf die Fahrtüchtigkeit haben.

Eine Zusammenfassung der internationalen Literatur zu diesem Gegenstand deckt auf:
– die Existenz gegensätzlicher Vermutungen, mit wissenschaftlichem Beweis, welcher eindeutig veränderte psychomotorische Funktionen aufzeigt;
– das Erfordernis, ausreichend komplexe psychomotorische Tests aufzunehmen, um die Auswirkungen niedriger Blutalkoholkonzentrationen aufzudecken;
– das Erfordernis, die Standardisierung experimenteller Studien über die Wechselwirkungen zwischen Mensch und Maschine zu verbessern;
– das Erfordernis, die folgenden Bereiche zu untersuchen: Alkoholtoleranz; geringe Blutalkoholkonzentrationen mit unerfahrenen Gelegenheitstrinkern einerseits und chronischen schweren Trinkern andererseits; die Auswirkungen des „Alkohol-Katers“; Beziehungen zwischen Alkohol, Geschlecht und Alter und spezifische Auswirkungen auf junge Fahrer; Alkohol-Drogen-Kombinationen.

Die Analyse der Gesetzgebungs- und Strafverfolgungs-Politiken deckt ebenfalls auf die Notwendigkeit für:
– Re-Evaluation der internationalen gesetzlichen Blutalkoholkonzentrationsgrenzen und Standardisierung der Maßnahmen zur Feststellung des Grades der Fahruntüchtigkeit;
– weitere wissenschaftliche Forschung, um ausgewählte gesetzliche Initiativen vor Ort in den meisten Staaten zu vergleichen und zu bewerten; Identifizierung der besten Strategien und Maßnahmen, um beeinträchtigte Fahrer zu erkennen und zu arrestieren; Bestimmung der optimalen Zufallstest-Rate, um abschreckende Wirkungen am Arbeitsplatz zu minimalen Kosten zu maximieren; Gestaltung innovativer und umfassender Maßnahmen für Rehabilitationsprogramme, welche für Untergruppen von Straftätern und Arbeitern benötigt werden; Untersuchung der Effektivität neuer Gesetzgebungen und Politiken.

Schlüsselwörter: Ethylalkohol – Niedrige Dosen – Verkehrssicherheit – Psychomotorische Leistung – Fahrtüchtigkeit

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Introduction

Alcohol tops the list of impairing substances in terms of extent of use, problem severity, accomplished research, and what is known about effects on performance. Directly and indirectly, traffic safety problems have given rise to a large proportion of such research, and traffic safety literature is a primary source of data about the broader topic of the effects of alcohol on performance. The role played by ethyl alcohol in causing accidents, and the correlation between blood alcohol concentrations (BACs) exceeding 80 mg/100 ml and driving impairment have consequently been confirmed by epidemiological studies [1–17]. Data from controlled laboratory studies [18–21] on alcohol using human subjects demonstrate and define impairment of skills important to safe performance. Deficits are both statistically significant and practically relevant.

From experiments which have examined lower alcohol levels, it is estimated that impairment of important skills also occurs at low BACs [22–59]. This conclusion, which appears to contradict recent statutory BAC limits, is partly due to more precise measurements of safety-critical skills.

However, much as it reflects both advances in technology and the measurement sophistication of a maturing area of study, the correlation between low BACs, driving impairment and accidents does not show scientific certainty, due to diverging interpretations.

This lack of certainty is even more evident in epidemiological studies, since it is difficult to correlate the effect of low BACs with road accidents, the causes of which are almost always multi-factorial.

In any case, improvement in research knowledge has implemented traffic safety policies, and major changes have occurred in traffic laws and enforcement over the last 10 years with regard to drinking and driving. Unfortunately, the relative efficacy of the many and varied legislative changes introduced by different states is still unknown.

The present review aims at examining the state-of-the-art regarding low BACs and driving impairment, partly with the intent of highlighting the methodological and interpretative problems underlying experimental studies, and also at examining current international legislation.

Studies on man-machine interaction

Experimental studies aimed at identifying variations in psychomotor functions caused by the intake of a psychoactive substance generally follow 3 methodological approaches, involving the use (combined or otherwise) of the following means:

– cars, modified in order to measure a series of parameters (regarding control over mechanical devices such as brakes, accelerator and steering; direction; speed, etc.), used on special circuits or on roads open to the public [60–64];

– driving simulators, i.e., computerized instruments simulating the environment, vehicle controls and habitual driving conditions, e.g. a route with obstacles to be avoided, etc. [20, 65–68];

– instrumentation and procedures which separately analyse changes in various functions which may all converge to make up psychomotor ability [21, 64, 66, 69–82]. In particular, these functions are visual (saccadic eye movements, changes in visual acuity and visual field), cognitive (attention, vigilance, memory, simple and complex associative functions, critical flicker fusion value), simple motor (tapping, reaction time, choice reaction time, one-dimensional tracking) and complex (two-dimensional coordination, multi-dimensional tracking, complex choice reaction time).

The use of various tests to explore one single psychomotor function and the assessment of different parameters within the same test are the direct consequence of the considerable number of tests which may be applied to the study of an exogenous factor. This explains why different laboratory studies carried out on identical substances often cannot reliably be compared or duplicated, and as a consequence the need for standardization of procedures [83–85], and the recent organization of 2 workshops promoted by the International Council on Alcohol, Drugs and Traffic Safety (ICADTS). The first of these workshops, "Drugs and Driving, Methodology in Man-Machine Interaction and Epidemiology Studies" [86], took place in Padova (Italy) in October 1991; the second, "Quality Assurance and Standardization Concerning Empirical Trials on Drugs and Driving" [87], the ideal continuation of the first, was held at Cologne (Germany) in 1992, during the 12th International Conference on Alcohol, Drugs and Traffic Safety.

The problem of the most suitable instruments and procedures for studying psychoactive substances also involves ethyl alcohol, above all when aiming at analysing low dose effects. Pharmacodynamic researches confirm that even small quantities of alcohol produce transitory changes in neuronal membranes and neurotransmitters (mainly dopamine-serotonin variations) leading to behavioural changes which rapidly disappear [88–95]. The literature also reveals that evaluation of the effects of low doses of ethyl alcohol requires the study of all psychomotor functions by means of all the above-mentioned tests.

Table 1 shows the types and methods used in the most recent studies and briefly describes the parameters providing indications on the design, contents and methodologies used for evaluating the conclusions of experimental studies.

In particular:

– sample size (number of subjects) influences the validity of the conclusions, since small sample numbers may lead to recurrent Type II errors (presence of an effect not recognized by the test);

– indication of the quantity of alcohol taken, in comparing alcohol dose and expected levels, allows verification of the "low levels" sought;

– indications of the ways in which alcohol levels in the biological substrate (blood, expired air, saliva) are determined allow the reliability of extrapolated BAC levels to be evaluated;

Table 1. Man-machine interaction for low blood alcohol levels: experimental measurements

Author	Year	No. subjects	Study design	Quantity alcohol	BAC (mg%ml), biological substrate	Test	Impairment	
							Yes	No
Landauer et al. [22]	1969	21	A	–	80	Pursuit rotor task		×
					expired air	Dot tracking task		×[a]
						Driving simulator		×
Staak et al. [23]	1972	15	A	0.65 g/kg	45	Tapping		×
					blood	Visual-acoustic reaction time	×	
						Hand-eye coordination test		×
						Attention test		×
						Critical flicker fusion		×
Linnoila et al. [24]	1974	90	A	0.5 g/kg	36–42	Choice reaction time		×
						Divided attention tracking	×	
						Coordination tests		×
Staak et al. [25]	1975	16	A	1 g/kg	70–80	Visual-acoustic reaction time	×	
					blood	Hand-eye coordination test	×	
						Attention test	×	
Staak and Eysselein [26]	1976	15	A	0.5 g/kg	20–30	Psychomotor coordination	×	
					blood	Hand-eye coordination test		×
						Attention test		×
						Visual-acoustic reaction time	×	
						Cognitive test		×
Lutze and Schacher [27]	1979	40	E	0.5 g/kg	49	Reaction time	×	
Richter and Hobi [28]	1979	14	E	0.39 g/kg	42	Critical flicker fusion		×
					blood,	Attention test		×
					expired air	Visual-acoustic reaction time		×
Flanagan et al. [29]	1983	46	D	–	30–60	Driving test	×	
					expired air,			
					blood			
Linnoila et al. [30]	1983	12	A	0.8 g/kg	–	Continuous performance task	×	
						Verbal memory	×	
Warrington et al. [31]	1984	6	A	0.4 g/kg	33	Critical flicker fusion		×
					blood	Choice reaction time	×	
						Digit span memory		×
Moskowitz et al. [32]	1985	10	B	–	15–30–45–60	Divided attention tracking	×	
					expired air	Information processing task	×	
Miles et al. [33]	1986	15	B	–	36	Tracking task	×	
					expired air	Vigilance task	×	
Cohen et al. [34]	1987	12	A	25 g	43	Visual reaction time	×	
					expired air	Adaptive tracking task		×
						Body sway	×	
Maylor et al. [35]	1987	36	B	0.33 g/kg	29	Choice reaction time		×[a]
					expired air	Visual search task		×
Rohrbaugh et al. [36]	1988	12	B	0.45–0.8 g/kg	40–70	Vigilance test	×	
					expired air			
Golby [37]	1989	48	A	0.5 g/kg	–	Choice reaction time	×	
						Gross bodily CRT	×	
						Critical flicker fusion	×	
						Soccer test		×[a]
Lukas et al. [38]	1989	20	C	0.56 g/kg	–	Digit symbol substitution test	×	
					expired air	Body sway	×	
						Finger tapping speed		×
						Hand steadiness		×
Marks and MacAvoy [39]	1989	12	A	0.94 g/kg	48	Divided attention	×	
					expired air			
Maylor et al. [40]	1989	22	D	0.63 g/kg	60–70	Choice reaction time	×	
					expired air	Choice response test		×
Mongrain and Standing [41]	1989	72	D	0.27 g/kg	–	Videogame (raquetball)		×
						Videogame (driving)		×
						Signal detection task		×

Table 1 (continued)

Author	Year	No. subjects	Study design	Quantity alcohol	BAC (mg%ml), biological substrate	Test	Impairment	
							Yes	No
Berlin et al. [42]	1990	24	A	–	60	Choice reaction time	×	
						Body sway	×	
						Critical flicker fusion	×	
						Short term memory	×	
						Digit symbol substitution test		×
Farrimond [43]	1990	21	D	0.35 g/kg	40	High level visual perception	×	
Gustafson and Kallmen [44]	1990	48	D	0.79 g/kg	68–82 expired air	Stroop's color word test		×
Gustafson and Kallmen [45]	1990	54	D	0.79 g/kg	67–73 expired air	Stroop's color word test		×
						Dot test	×	
						Pin test		×
Hill and Toffolon [46]	1990	10	D	30.6 g	61 blood	Visual acuity		×
						Visual fields	×	
						Color vision		×
						Stereovision		×
						Accomodation	×	
						Convergence	×	
Hindmarch et al. [52]	1991	18	A	0.25 0.50 g/kg 0.75 1.00 g/kg	–	Choice reaction time	× (>0.50)	
						Compensatory tracking task	× (>0.75)	
						Critical flicker fusion	× (>0.75)	
						Short term memory		×
Horne and Baumber [53]	1991	12	A	95 ml, 40%	65–72 expired air	Driving simulator	×	
Horne and Gibbons [54]	1991	8	A	–	35–70 expired air	Wilkinson auditory vigilance task	×	
Kerr and Hindmarch [55]	1991	10	A	30 g	≅60	Choice reaction time	×	
						Compensatory tracking task		×
						Critical flicker fusion		×
						Short term memory	×	
Lyvers and Maltzmann [56]	1991	80	D	–	50 expired air	Wisconsin card sorting test	×	
Schuckit et al. [57]	1991	48	B	0.70 g/kg	90 blood	Body sway	×	
						Dowell balancing test	×	
						Free recall	×	
						Trail making test	×	
Tornros and Laurell [58]	1991	24	–	–	150 expired air	Driving simulator	×	
					40 expired air	Driving simulator	×	
Pickworth et al. [59]	1992	6	A	0.625 g/kg	50 expired air	Hand-eye coordination test		×
						Logical reasoning task		×
						Rapid arithmetic task		×
Kuitunen et al. [47]	1990	12	A	0.8 g/kg	–	Tracking	×	
						Body sway	×	
						Divided attention	×	
						Digit symbol substitution	×	
						Symbol copying	×	
Linnoila et al. [48]	1990	8	A	0.8 g/kg	70 expired air	Tracking task	×	
						Choice reaction time		×
						Non verbal information proc.		×
						Continuous performance task	×	
						Verbal memory		×
Linnoila et al. [49]	1990	10	A	0.8 g/kg	70 expired air	Tracking task	×	
						Choice reaction time		×
						Non verbal information proc.		×
						Continuous performance task	×	
						Verbal memory		×

Table 1 (continued)

Author	Year	No. subjects	Study design	Quantity alcohol	BAC (mg%ml), biological substrate	Test	Impairment	
							Yes	No
Maylor et al. [50]	1990	20	D	0.63 g/kg	60–77 expired air	Visual tracking task (D.A.)	× (D.A.)	×
						Auditory detection task	×	
Girre et al. [51]	1991	12	A	0.5 g/kg	75 expired air	Visual reaction time	×	
						Auditory reaction time	×	
						Thurstone arithmetic test	×	
						Digit symbol substitution test	×	
						Two symbol cancellous test	×	
						Short term recall	×	
						Point counting test	×	

A = Double blind, crossover, placebo-controlled; B = single-blind, crossover, placebo-controlled; C = double blind, randomized, placebo-controlled; D = single blind, randomized, placebo-controlled; E = repeated measures, crossover; D.A. = divided attention
[a] Improvement in function examined

– full details of the tests used reveal considerable variability and an almost total lack of standardization.

Most of the reviewed works are double-blind trials with cross-over. In about 50% of these studies, the authors used alcohol as a verum (i.e. a substance definitely causing impairment of the functions studied), with the aim of comparing effects on psychomotor functions with those of pharmacologically active substances belonging to various classes (e.g. benzodiazepines, non-steroidal anti-inflammatory drugs, antidepressants) or of determining possible interactions between alcohol and such substances. In all cases, results were evaluated by statistical analysis.

Analysis of the studies reviewed and reported in Table 1 shows frequent discrepancies between results and interpretations, e.g. some authors believe that cognitive and motor functions are compromised, others report a plateau of test results after alcohol intake, and yet others report improved driving ability as a result of the disinhibiting effect of alcohol. These discrepancies lead to two types of problem, current and unresolved, as follows:
– identification of the most suitable study methods and procedures for analysis of the effects of alcohol and exogenous substances on psychomotor performance (laboratory tests, driving simulators, road tests);
– determination of the BAC-induced psychomotor changes which significantly impair the driving ability of a hypothetical "average subject".

In spite of possible defects in designing and conducting experiments, the lack of homogeneity in methods, and the various degrees of sensitivity of the tests used (all causing frequent discrepancies in conclusions), the present review did find general agreement on the following assumptions:

1) the psychomotor functions explored are sensitive to the effects of low alcohol levels; tests requiring suitably complex psychomotor performance are required in order to highlight the impairment of such functions. This is in agreement with recent reports [96–98];

2) most authors agree that low alcohol levels can cause significant impairment in psychomotor performance, to the extent that driving safety is compromised;

3) there is justification for critical reconsideration of the maximum BAC levels for driving in the legislation of many countries.

Legislation

The current international situation reveals an interesting trend [98].

In European (Holland, Sweden, Switzerland) and North American (USA, Canada) countries, where highly structured programs for prevention and enforcement are adopted, morbidity and deaths due to alcohol-related road accidents are slowly and constantly decreasing [99–103].

In some countries, the conclusions of research groups on the role of low alcohol levels have been accepted and incorporated in legislative measures (Table 2 [104]) which have led to lowered BAC levels: from 100 to 80 mg % in some American states [98, 105], from 80 to 50 mg% in Australia [106], and from 50 to 20 mg% in Sweden [107]. In other legislations (USA, Canada), laws have been introduced which, although leaving the BAC threshold unchanged, involve sanctions for those stopped while driving with BAC values near the legal limit or for drivers belonging to certain categories (e.g. young and/or newly licensed drivers, commercial drivers). For instance, in the state of Ontario, Canada, for the last 10 years, drivers have risked immediate confiscation of their licence for 12 hours if their BACs fall between 50 and 80 mg% which, although less than the legal limit of 80 mg%/ml, is considered potentially dangerous [108]. Some researchers disagree on the efficacy and usefulness of such measures, believing that excessive restrictions end up by being partially rejected both by the target population (drivers) and by the police authorities applying them [107]. Instead, other authors report the great reduction in the numbers of drivers stopped with BACs between 50 and 80 mg % as a consequence of the introduction of new regulations [106].

In the wake of such results, it is to be hoped that uniform regulations will rapidly be introduced, at least in EC countries. Such regulations must satisfy traffic safety requirements, following the example of countries (e.g. Germany, Netherlands) in which legislation in terms of prevention, enforcement and rehabilitation is more advanced and implementation carried out with greater efficiency. This would help to overcome the legislative and applicational hindrances which in some countries create situations in which existing regulations are not respected.

Table 2. International legislation on drunken driving[a]

Country	BAC threshold (mg%ml)	Breath test	Blood test	Medical examination
Austria	80	Yes	Yes	Yes
Belgium	50	Yes	Yes	–
Denmark	80/120	Yes	Yes	Yes
Finland	50/150	Yes	Yes	Yes
France	80	Yes	Yes	Yes
Germany	80/110	Yes	Yes	Yes
Great Britain	80	Yes	Yes	–
Eire	100	Yes	Yes	Yes
Holland	50	Yes	Yes	–
Hungary	0	Yes	Yes	–
Italy	80	Yes	Yes	Yes
Jugoslavia	50	–	–	–
Luxembourg	80/120	Yes	Yes	Yes
Norway	50	Yes	Yes	–
Poland	20/50	Yes	Yes	–
Portugal	50	Yes	–	–
Romania	0	Yes	Yes	Yes
Spain	80	Yes	Yes	Yes
Sweden	20	Yes	Yes	Yes
Switzerland	80	Yes	Yes	Yes
Canada	80[b]	Yes	Yes	Yes
United States	100[c]	Yes 23 states	Yes 45 states	–
Australia	80[d]	Yes	Yes	Yes
New Zealand	80/120	Yes	Yes	–
Japan	50	–	–	–

[a] From Ferrara SD, 1988 [104], modified
[b] 12 hours' licence suspension for BAC between 50 and 80 mg%ml in state of Ontario
[c] 40 mg%ml for commercial vehicle drivers. Thresholds between 0 and 80 mg%ml for young drivers in 19 states; 80 mg%ml in 6 states
[d] 50 mg%ml in state of Victoria and Canberra ACT

Conclusions

It is now evident that performance changes begin with departure from zero BAC. The exact point on the ascending BAC curve at which the changes become significantly impairing is, within broad limits, a function of task demands, individual skill, and individual tolerance to alcohol. However, all performance is susceptible to impairment at some level, although there are great differences between drinkers and skills and the BACs at which significant impairment occurs. Simple sensory functions, perceptual and attention processes, information processing, co-ordination, balance, and a variety of over-learned, highly-practised skills critical to safe performance, are sensitive or relatively resistant to alcohol, and the BAC at which they are affected reflects the individual's tolerance to alcohol. Consequently, although the impairment effects of alcohol have been well researched, missing knowledge in the area merits investigation on the following: tolerance; low BACs with inexperienced, infrequent drinkers and chronic, heavy drinkers; hangover effects; alcohol-gender-age interactions, and specific effects on young drivers; alcohol-drug combinations.

A number of other general guiding principles emerge in experimental research on alcohol. The first is that experimental research should be related to the real world, in order to link laboratory results to field observation reflecting drivers' actual reality, often affected by other impairing conditions, such as fatigue, use of drugs, etc. The second principle is a call for the development of additional, reliable, cheap, quick and portable tests to better measure performance and fitness for duty involving many factors beyond psychomotor tasks, such as judgement and decision-making.

A third principle is that, because a great deal of research has been carried out in psychopharmacology, new research should only fill in the gaps in current knowledge. Currently, research is being conducted by many different groups and is rather fragmentary. International collaboration may be a way to properly review the large body of literature, identify the remaining major gaps in the body of information and precede investment in new studies, and establish an internationally accepted format/design for measuring performance impairment related to the real world of drinking and driving.

In the field of social intervention strategies, drinking and driving has been historically perceived as a form of criminal behaviour instead of the natural consequence of a driving and drinking society. The legal control system is based on a deterrence theory, which postulates that sure, swift, and severe punishment should prevent people from engaging in a particular sanctioned activity. Both the system of traffic laws and enforcement and the workplace environment function on the premise that the threat of detection and punishment should act as an effective deterrent. In the 1980s, several states introduced many and varied legislative changes, but the relative efficacy of some of these changes is unknown. Most legislative changes strengthen the role of "driving while intoxicated" (DWI) programs, and specific and general deterrence.

Specific deterrence seeks, through punishment education and treatment, to influence drinking drivers who have already been apprehended to refrain from drinking and driving in the future. Roadside surveys indicate that most drinking drivers in the USA have low BACs [109]. In contrast, a significant portion of fatally injured American drivers have high BACs [110]. Research has also shown that drivers fatally injured in alcohol-related crashes are more likely to have a history of DWI convictions [111, 112] and that an increasing proportion of drivers arrested for DWI are recidivists [113].

In apparent contrast with these figures, the last decade in the United States, Canada and Europe [99, 101, 103, 114] has also brought about significant progress in reducing the toll of transportation crashes due to abuse of alcohol and other drugs. For example, in USA in 1982, 57% of all highway fatalities were alcohol-related. By 1992, that figure had dropped to 45.8%. This means that the variety of legislative innovations currently adopted by several American states needs more comprehensive consideration and implementation of research in the area of intervention strategies. However, the decrease in the frequency of the drinking-driving phenomenon, reported in many industrialized countries, must be evaluated critically, since it may be the consequence of reduced vigilance by police in actuating repression policies, or the result of changes in the types of psychoactive substances taken.

Further research is needed to: assess the effects of advertising and health promotion campaigns on both alcohol consumption and drinking-driving behaviour; compare and evaluate selected legislative initiatives currently in place in most states; identify the best strategies and procedures to detect and arrest impaired drivers and the amount of detection required to produce deterrence; determine the optimum random testing rate to maximize deterrent effects at minimal cost in the workplace; determine the optimal specific deterrence of various sanctions ranging from vehicle impoundment to mandatory treatment programs; design innovative and comprehensive approaches to rehabilitation programs needed for sub-groups of offenders and workers; study under-age drinking, patterns of alcohol use and sale, social impact of control issues and methods of increasing the effectiveness of new legislations and policies.

In conclusion, it is clear that within the research approaches of experimentation and evaluation of legislative and intervention strategies, there is still much work to be done. Creative and international synergistic work on prior-designed scientific projects may be the best answer for the next decade.

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