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OSHA's Enforcement of Asbestos Standards in the Construction Industry

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Abstract

Background: Exposure to asbestos continues to be a concern for workers in the construction industry. Asbestos can still be found in many construction products and in hundreds of thousands of buildings in the United States. Methods: Data from OSHA's Integrated Management Information System (IMIS) were used to identify inspections in which violations of OSHA's asbestos standards were cited from 2010 to 2012. Employers selected for analysis had NAICS codes in the construction industry sector. Descriptive statistics were used to describe the characteristics of OSHA's enforcement approach to asbestos standards violations in the construction industry. Nonparametric statistics were used to identify significant differences in penalties assessed for violating asbestos standards based upon the type of violation and the type of inspection. Results: This study identified 4017 violations from 846 inspections in which the asbestos standards were cited in the construction industry. Employee complaints and referrals resulted in the largest number enforcement activities. Significant differences were identified in the fines assessed for different types of violations and inspections. Site preparation contractors, residential construction, and commercial and institutional building construction trades experienced the greatest number of violations. Most frequently cited standards included employees performing work in areas that were not properly regulated, personal protective equipment not meeting standards, and employee training not meeting standards. Conclusions: Recommended control measures include conducting targeted inspections in construction industry trades with a greater potential exposure to asbestos, improving worker awareness of asbestos and its hazards, strengthening the fining structure for asbestos violations, and conducting further research to determine underlying reasons for employers' inability to comply with OSHA's asbestos standards.

Keywords

Asbestos, Construction Industry, OSHA, Enforcement

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1. Introduction

Over the years, the use of asbestos in the United States has declined substantially and mining of asbestos in the United States ceased in 2002 [1]. However, many asbestos products remain in use and new asbestos-containing products continue to be manufactured in or imported into the United States [1]. Exposure to asbestos is a great concern especially for people working in the construction industry. The presence of asbestos in construction materials from use decades ago, the continued use of asbestos containing materials not banned today in the United States, and work activities that require workers to disturb asbestos containing materials through demolition, alterations, and construction activities add up to increased chances for exposure to airborne asbestos.

To protect workers from asbestos exposure, the Occupational Safety and Health Administration (OSHA) has adopted the asbestos standards for the construction industry, 29 CFR 1926.1101 [2]. The OSHA standards apply to asbestos family of materials of chrysotile, amosite, crocidolite, tremolite asbestos, anthophyllite asbestos, actinolite asbestos, and any of these minerals that have been chemically treated and/or altered [2]. The standards do not apply to asbestos-containing asphalt roof coatings, cements and mastics [2]. The OSH Act is enforced by the federal OSHA in 29 states while 21 states have state plans which meet or exceed the requirements of federal OSHA [3].

The OSHA asbestos standards establish requirements for monitoring, measuring, and protecting workers who may potentially be exposed. Most OSHA state plan states adopted the 29 CRF 1926.1101 federal OSHA standards. Two states, California (CAL/OSHA) and Washington State (WISHA) have their own standards for asbestos in the construction industry [4].

In addition to promulgating standards, OSHA has the responsibility of ensuring safe and healthful workplaces through enforcement efforts. These workplace inspections can be initiated through a number of avenues ranging from planned inspections in which the site falls under a targeted OSHA inspection priority to employee complaints and referrals. OSHA also has established inspection priorities with their number one priority being imminent dangers followed by fatalities, catastrophes, and accidents [5]. Employers on the other hand, have the responsibility to protect their employees from the hazards of asbestos and federal OSHA and state OSHA plans have the responsibility of enforcing the asbestos safety standards. The purpose of this study was to examine the enforcement of occupational safety and health standards for asbestos in the construction industry. With a better understanding of how these standards are being enforced, recommend actions can be developed which, when implemented, can better protect workers.

2. Methodology

2.1. Data

The focus of this study was on the safety inspection and enforcement activities related to asbestos in the construction industry. Data from OSHA's Integrated Management Information System (IMIS) was analyzed for inspections conducted by the federal Occupational Safety and Health Administration and the agencies enforcing state plan occupational safety and health standards. The IMIS system contained data from both federal OSHA states and state plan states. Inspection data and violation data in which violations of OSHA's 29 CFR 1926.1101, CAL/OSHA's, Title 8 Section 1529, or WISHA's WAC 296-62-07705 were cited were included for analysis. Inspections were conducted between January 1, 2010 and December 31, 2012 involving employers with NAICS codes falling in the construction industry sector.

The following variables from the IMIS records were examined in this study:

Asbestos Standard Violated: The specific asbestos standard number that was violated was identified. The standard numbers selected for this study included OSHA's 29 CFR 1926.1101, CAL/OSHA's Title 8 Section 1529, and WISHA's WAC 296-62-077.

Penalties: The current penalty assigned to each standard violated was identified. Current penalties are the penalties assessed following any reductions or deletions from administrative actions such as informal conferences.

Type of Inspection: The type of inspection was classified as follows [6]:

Fatalities and Catastrophes—Incidents that involved a death or the hospitalization of three or more employees.

Complaints—Allegations of hazards or violations by employees.
Referrals—Referrals of hazard information from other federal, state or local agencies, individuals, organizations or the media receive consideration for inspection.
Follow-Ups—Checks for abatement of violations cited during previous inspections conducted by OSHA in certain circumstances.
Planned or Programmed Investigations—Inspections aimed at specific high-hazard industries or individual workplaces that have experienced high rates of injuries and illnesses.
Unprogrammed Related Investigations—Inspections of employers at multi-employer work sites whose operations are not directly affected by the subject of the conditions identified in the complaint, accident, or referral.

Type of Violation: The violations were classified according to their severity according to the following OSHA classification system [5]:
Willful Violation: A *willful* violation exists where the evidence shows either an intentional violation of the Act or plain indifference to its requirements.
Repeat Violation: A repeated violation exists if that employer has been cited previously for a substantially similar condition and the citation has become a final order.
Serious Violation: A serious violation exists when a hazard causes or was likely to cause death or serious physical harm.
Other-Than-Serious Violation: An other-than-serious violation is cited in situations where the most serious injury or illness that would be likely to result from a hazardous condition cannot reasonably be predicted to cause death or serious *physical* harm to exposed employees but does have a direct and immediate relationship to their safety and health.

NAICS Code: The North American Industrial Classification System (NAICS) code for the establishment site as determined by OSHA was used to classify establishments by industry sector. The construction industry consists of industry sectors with NAICS codes that range from 230000 to 238990.

Number of Employed Persons: The number of employed persons over the three year period was obtained using the Bureau of Labor Statistics Current Population Survey.

2.2. Statistical Analyses

Data was analyzed descriptively to summarize the number of asbestos standard violations by industry, the type of inspection conducted, the standard number that was violated, and the type of violation. Penalties assessed for asbestos violations were summarized by type of inspection, standard number, and type of violation.

Because the distribution of penalties was not normally distributed, use of non-parametric statistical procedures was required. The Kruskal-Wallis test examines ranks across the categorical independent groups [7]. If all of the samples were from the same population, then the mixture of high, medium and low ranks should be evenly distributed across the groups [7].

The Kruskal-Wallis test was used in this study to identify the presence of significant differences in the mean rankings of penalties assessed across the different types of inspections. A second Kruskal-Wallis test was used to identify significant differences in the mean rankings of penalties assessed between the different asbestos violation categories. *Post hoc* Mann-Whitney U tests were used to identify significant differences between each of the pairwise groups [8].

3. Results

3.1. Type of Inspections

Data from the IMIS system identified 4017 violations from 846 inspections in which the asbestos standards were cited in construction industry establishments during the analysis period of January 1, 2010 to December 31, 2012. Employee complaints accounted for approximately 34.0 percent of all asbestos violations, referrals accounted for 22.8 percent, and planned inspections accounted for approximately 20.3 percent (see **Table 1**).

Overall, the average penalty assessed for a violation of an asbestos standard was $809. The average penalties ranged from $239 for violations classified as "Other-than-serious" to $9205 for violations classified as "Willful". A summary of the results appears in **Table 2**.

Table 1. Frequency, percentage, and average penalty of asbestos violations by inspection type (2010-2012).

Inspection Type	Descriptive Statistics		
	N	Percent	Average Penalty (USD) per Violation
Accident	5	0.1	343
Complaint	1365	34.0	1090
Referral	914	22.8	915
Follow Up	5	.1	1040
Unprogrammed-Related	744	18.5	558
Planned	815	20.3	537
Programmed-Related	156	3.9	402
Programmed-Other	6	.1	214
Unprogrammed-Other	7	.2	167
Total	4017	100.0	$809

Table 2. Frequency, percentage, and average penalty of asbestos violations by violation type (2010-2012).

Inspection Type	Descriptive Statistics		
	N	Percent	Average Penalty (USD) per Violation
Serious	3196	79.6	637
Other-Than-Serious	692	17.2	239
Repeat	18	0.4	1372
Willful	111	2.8	9,205
Total	4017	100.0	$809

3.2. Violations

An analysis of asbestos related inspections and violations identified the Site Preparation Contractor sector as having the largest percentage of asbestos inspections (20.2%) and the largest percentage of asbestos violations (24.8%) (see **Table 3**). However, this industry only accounted for less than 5 percent of all asbestos inspections and had an inspection rate of 8.29 inspections per 1000 employees which is below the overall inspection rate of 9.04 inspections per 100,000 employees. This industry comprises establishments primarily engaged in site preparation activities, such as excavating and grading, demolition of buildings and other structures, septic system installation, and house moving (BLS, 2014).

3.3. Industry Sector

The Commercial and Institutional Building Construction industry accounted for approximately 15.4 percent of all inspections and 19.3 percent of all inspections resulting in asbestos violations. This industry was the second highest in terms of the frequency of both all inspections and asbestos related inspections. Residential Remodelers were the third most frequently cited industry for asbestos violations accounting for approximately 12.9 percent of all asbestos inspections and 13.3 percent of all asbestos violations. However, this industry accounted for less than 3 percent of all inspections. An analysis of all inspections in construction industry NAICS code found the roofing industry accounted the most inspections overall with approximately 16.2 percent of all inspections but less than 9 percent of all asbestos violations and less than 9 percent of inspections resulting in asbestos violations.

Table 3. Frequency, percentage, and average penalty of asbestos violations by violation type (2010-2012).

Industry Name and NAICS Code	Inspections per 1000	All Inspections		Asbestos Inspections		Asbestos Violations	
	Employees	N	%	N	%	N	%
New Single-Family Housing Construction (236,115)	6.45	5531	3.8	37	4.4	110	2.7
New Multifamily Housing Construction (236,116)	44.23	2864	2.0	10	1.2	44	1.1
New Housing For-Sale Builders (236,117)	3.26	225	0.2	2	0.2	8	.2
Residential Remodelers (236,118)	4.71	3427	2.4	109	12.9	533	13.3
Industrial Building Construction (236,210)	5.49	2467	1.7	11	1.3	54	1.3
Commercial and Institutional Building Construction (236,220)	15.02	22,524	15.7	163	19.3	752	18.7
Water and Sewer Line and Related Structures Construction (237,110)	12.53	5725	4.0	9	1.1	47	1.2
Power and Communication Line and Related Structures Const. (237,130)	2.09	873	0.6	1	0.1	3	0.1
Land Subdivision (237,210)	0.73	102	0.1	4	0.5	13	0.3
Highway, Street, and Bridge Construction (237,310)	8.54	7299	5.1	3	0.4	9	0.2
Other Heavy and Civil Engineering Construction (237,990)	6.12	1766	1.2	1	0.1	1	0.0
Poured Concrete Foundation and Structure Contractors (238,110)	8.52	2617	1.8	3	0.4	12	0.3
Structural Steel and Precast Concrete Contractors (238,120)	22.64	3152	2.2	1	.1	2	0.0
Framing Contractors (238,130)	57.06	9065	6.3	16	1.9	50	1.2
Masonry Contractors (238,140)	23.63	9182	6.4	7	0.8	38	0.9
Glass and Glazing Contractors (238,150)	6.86	979	0.7	6	0.7	29	0.7
Roofing Contractors (238,160)	47.93	23,411	16.3	73	8.6	351	8.7
Siding Contractors (238,170)	29.00	2701	1.9	5	0.6	63	1.6
Other Foundation, Structure, and Building Exterior Contractors (238,190)	8.65	936	0.7	3	0.4	11	0.3
Electrical Contractors and Other Wiring Installation Contractors (238,210)	3.66	7909	5.5	38	4.5	161	4.0
Plumbing, Heating, and Air-Conditioning Contractors (238,220)	2.87	6938	4.8	59	7.0	283	7.0
Other Building Equipment Contractors (238,290)	2.74	974	0.7	4	0.5	21	0.5
Drywall and Insulation Contractors (238,310)	6.88	4046	2.8	19	2.2	35	0.9
Painting and Wall Covering Contractors (238,320)	7.16	3543	2.5	13	1.5	69	1.7
Flooring Contractors (238,330)	3.79	660	0.5	22	2.6	148	3.7
Finish Carpentry Contractors (238,350)	5.08	1659	1.2	5	0.6	17	0.4
Other Building Finishing Contractors (238,390)	7.82	1439	1.0	6	0.7	41	1.0
Site Preparation Contractors (238,910)	8.29	6566	4.6	171	20.2	997	24.8
All Other Specialty Trade Contractors (238,990)	6.81	5234	3.6	45	5.3	115	2.9
Total	9.04	143,814	100.0	846	100.0	4017	100.0

3.4. Asbestos Standard Violated

An analysis of violations by asbestos standard was performed for the three groups of standards; OSHA's 1926.1101 standards, CAL/OSHA's 1529 asbestos standards, and WISHA's 296-62-077 asbestos standards. During the analysis period, there were 3360 violations of the 1926.1101 asbestos standards cited. The most frequently cited sections the standards included violations of the requirements for asbestos work to be conducted in regulated areas, lack of employee training, personal protective equipment (PPE) violations, and a lack of monitoring and exposure assessment (see **Table 4**).

Similar results were identified for the leading CAL/OSHA 1529 standards cited. Overall, there was 123 violations of the 1529 standards with the most frequently cited sections including violations of the requirements for exposure assessment, regulated work areas, employee training, PPE, and control measures. Frequently cited violations of the WISHA standards included violations of standards pertaining to the communication of hazards, monitoring criteria, PPE, and employee training. Overall, there were 534 violations of the asbestos standards identified for the analysis period. Because of the degree of hazards associated with willful violations and the penalties they can carry, an analysis of willful violations of the asbestos standards was conducted. Most frequently cited standards in which willful violations were identified include standards pertaining to work in regulated areas, employee training, monitoring, and respiratory protection.

3.5. Inferential Tests

Kruskal-Wallis tests were conducted to determine if significant differences in mean rankings of penalties assessed for asbestos violations exist between the types of violations. The data met the assumptions of the test procedure as described in the Methods section. There were 4,017 cases in the analysis. The Kruskal-Wallis test identified significant differences in the mean ranks of the penalties assessed by type of violation ($X^2 = 133.15$, d.f. = 3, $p < 0.000$) (see **Table 5**). *Post hoc* tests using Mann-Whitney U tests identified significant differences between pairwise mean rankings (see **Table 6**). These *post hoc* tests identified significant differences between the mean rankings for all pairs except for the mean ranking of penalties assessed for repeat violations compared to willful violations. Significant results indicate the penalties differ significantly between groups.

Kruskal-Wallis tests also identified significant differences in the mean rankings of the penalties assessed by type of inspection ($X^2 = 48.49$, d.f. = 8, $p < 0.001$) (see **Table 7**). Mann-Whitney U *post hoc* tests identified a number of significant differences between pairs of mean rankings (see **Table 8**). Mean rankings for penalties assessed were significantly different for follow up inspections compared to all other types of inspections. Complaint and referral inspections penalties were significantly different. Other pairwise comparisons had mixed results.

4. Discussion

Exposure to asbestos poses a major health hazard to workers in the construction industry despite efforts to eliminate its use. While there have been a number of bans on the use asbestos enacted in the United States, it is still

Table 4. Most frequently cited 1926.1101 standards (2010-2012).

Standard	N	Percent (Total N = 3360)
Class I, II, and III asbestos work conducted in regulated areas (1926.1101 E01)	226	6.7
Employee training (1926.1101 K09 I)	167	5.0
Protective clothing (1926.1101 I01)	160	4.8
Initial exposure assessment (1926.1101 F02I)	146	4.4
Duties of employers, identify ACM materials (1926.1101 K03 I)	118	3.5
Competent person (1926.1101 E06)	109	3.2
Methods of compliance, engineering controls and work practices (1926.1101 G01)	98	2.9
Class III controls (1926.1101 G08III)	92	2.7
Class I work, less than 25 linear feet or 10 square feet (1926.1101 J02I)	90	2.7
Respiratory protection (1926.1101 H01)	89	2.7
Total	1,295	38.5

Table 5. Mean rankings of penalties assessed by type of violation.

Type of Violation	N	Percent Mean Rank
Serious	3196	2079.36
Other-Than-Serious	692	1607.84
Repeat	18	2877.75
Willful	111	243.10
Total	4017	

Table 6. Mann-whitney u pairswise comparisons: significance of mean rankings of penalties by type of violation.

Type of Violation	Serious	Other-Than-Serious	Repeat
Serious	-		
Other-than-Serious	0.002	-	
Repeat	0.000	0.000	-
Willful	0.000	0.003	0.571

Table 7. Mean rankings of penalties assessed by type of violation.

Type of Inspection	N	Percent Mean Rank
Accident	5	2614.30
Complaint	1365	2058.07
Referral	914	2124.90
Follow Up	5	3108.30
Unprogrammed-Related	744	2002.21
Planned	815	1838.08
Programmed-Related	156	1802.79
Programmed-Other	6	1639.67
Unprogrammed-Other	7	1623.43
Total	4017	

Table 8. Mann-whitney u pairswise comparisons: significance of mean rankings of penalities by type of inspection.

Type of Inspection	Accident	Complaint	Referral	Follow Up	Unprogrammed-Related	Planned	Programmed-Related	Programmed-Other
Accident	-							
Complaint	0.296	-						
Referral	0.352	0.200	-					
Follow Up	0.108	0.052	0.041	-				
Unprogrammed-Related	0.151	0.242	0.041	0.014	-			
Planned	0.085	0.000	0.000	0.004	0.001	-		
Programmed-Related	0.045	0.006	0.001	0.004	0.027	0.623	-	
Programmed-Other	0.202	0.304	0.207	0.022	0.348	0.578	0.717	-
Unprogrammed-Other	0.186	0.340	0.283	0.022	0.407	0.631	0.778	0.861

present in many forms of construction materials found in hundreds of thousands of existing buildings. This study examined OSHA's enforcement of the asbestos standards in the construction industry.

Over the three year analysis period this study covered, OSHA cited violations of the asbestos standards over 4000 times in 809 inspections. Employers engaged in site preparation trades, which includes demolition-related activities, were cited most often. However, the inspection rate based upon the number of workers was far less than many other construction industries. It appears there is a focus by OSHA on conducting inspections in industries such as the roofing industry, framing industry, and multi-family construction industry and less of a focus on the industries identified with the higher numbers of asbestos violations. To better protect workers, industries with greater exposures to asbestos should receive a higher inspection priority.

The extent to which OSHA conducts planned inspections and enforces the asbestos standards does not appear to be representative of the potential exposure in the construction industry. It appears the majority of OSHA's enforcement activities related to the asbestos standards were the result of employee complaints and referrals. These complaints and referrals accounted for more than half of all asbestos-related inspections and violations.

For OSHA's complaint inspection process to be more effective, employees must be knowledgeable of the asbestos standards, know the hazards of asbestos exposure, have skills for recognizing asbestos sources in the workplace, and be knowledgeable of OSHA's role in enforcing standards. Education and awareness programs could strengthen the enforcement of the asbestos standards by increasing workers' awareness and action resulting in higher numbers of worker complaints and corresponding enforcement activities.

Planned inspections on the other hand, while accounting for the largest percentage of willful violations, yielded less than one quarter of all asbestos violations. To strengthen the inspection process, targeting the industry groups with planned inspections focused on asbestos could have a positive impact on protecting workers. The site preparation industry group was identified as one potential focus industry due to asbestos exposure from demolition activities. The residential construction and the commercial and institutional building construction also had a disproportionate number of inspections compared to the number of asbestos-related inspections and should also be included as a sector for increased planned inspections focused on asbestos.

An examination of penalties determined OSHA's citation and penalty process resulted in the largest penalties assessed for willful violations. The higher fines can be expected for the willful violations because OSHA's penalty system establishes this practice. Of concern, however, is the fact that willfully exposing workers to asbestos in the construction industry resulted in an average penalty that was less than $10,000 per violation. Serious violations of asbestos standards resulted in average penalties less than $1000. A criticism of OSHA for decades has been the penalties assessed for violating OSHA standards that do not appear to match the potential severity of the long-term effects of exposure and do not serve as a true deterrent.

To protect workers, employers are required to comply with the asbestos standards. Whether it is a federal OSHA site or a state plan site, the requirements are, for the most part, the same. In fact, for many state plan states, their standards are identical to the federal standards. An analysis of the asbestos standards cited yielded similar results across these federal and state plans. Common violations included exposing workers to asbestos because regulated areas were not established, exposure monitoring was not properly conducted, and appropriate control measures were not used. The more serious violations classified as being willful included work being conducted in areas that were not regulated, a lack of exposure monitoring, a lack of PPE, and inadequate employee training. The reasons why employers failed to comply with these standards were not within the scope of this study but should be the focus of future research.

References

[1] Centers for Disease Control and Prevention (CDC) (2011) Current Intelligence Bulletin 62: Asbestos Fibers and Other Elongate Mineral Particles: State of the Science and Roadmap for Research. Centers for Disease Control and Prevention, Washington DC. http://writingcenter.waldenu.edu/706.htm

[2] Occupational Safety and Health Administration (OSHA) (2014) 29 CRF 1926.1101: Asbestos. Washington DC.

[3] Occupational Safety and Health Administration (OSHA) (2014) Frequently Asked Questions about State Occupational Safety and Health Plans. Washington DC. https://www.osha.gov/dcsp/osp/faq.html

[4] California Division of Occupational Safety and Health (CAL/OSHA) (2014) Title 8, Section 1529: Asbestos. California Division of Occupational Safety and Health, Oakland, CA.

[5] Occupational Safety and Health Administration (OSHA) (2011) CPL 02-00-150: Field Operations Manual (FOM).

Washington DC.

[6] U.S. Department of Labor: Occupational Safety and Health Administration (OSHA) (2014) Fact Sheet, OSHA Inspections. Washington DC.

[7] Sprent, P. and Smeeton, N. (2007) Applied Nonparametric Statistical Methods. Chapman & Hall, Boca Raton, FL.

[8] Hayes, W. (1988) Statistics. Holt, Reinhart, and Winston, Inc., Chicago, IL.

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A Novel Application of Inertial Measurement Units (IMUs) as Vehicular Technologies for Drowsy Driving Detection via Steering Wheel Movement

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Abstract

Introduction: Vehicular technologies intended for the improvement of driver safety are especially critical today in the view of the thousands of deaths that occur annually due to drowsy driving. Current technologies include physiological methods like electroencephalography (EEG), behavioral methods including driver video monitoring, and vehicle measures which include lane and steering wheel tracking. These current technologies are impractical in their current implementations as they cannot readily be used outside of laboratory settings due to their requirements for intrusive electrodes, expensive cameras, and complex equipment. An earlier article demonstrated an effective method for wheel tracking using only an accelerometer; however the introduction of integrated gyroscopes and accelerometers has afforded further opportunities. Objective: This paper introduces a novel, low-cost, and easy to implement an approach to address this unmet problem. Method: Through the use of an Inertial Measurement Unit (IMU) combining a gyroscope and an accelerometer, measurements of steering wheel behavior were recorded in both simulator and real world driving while compared against a standard potentiometer. Results: The excellent agreement between potentiometer recorded angles and IMU estimated angles ($R^2 = 0.98$, $P < 0.001$) suggests that the complicated installation of potentiometers in vehicle steering columns is no longer a necessary step for steering wheel monitoring. Conclusion: This paper presents an IMU based method for drowsy steering-wheel behavioral tracking which is cost-effective, easy to implement, and accurately estimates steering behaviors. The results suggest that this novel vehicle technology offers hope for improving road safety.

Keywords

Driver Safety, Drowsy and Fatigued Driving, Accidents, Accident Prevention, Inertial Measurement

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Units

1. Introduction

Many methods have been proposed for the detection of drowsy or fatigued driving. Researchers have tried physiological measures which include heart rate, breathing rate, and brain activity via electroencephalography (EEG). Behavioral measures including eye blinks and eye closures have also been used. Because these measures have obtrusive properties, they are impractical for daily use with commuters and researchers have turned to vehicle-based measures instead. Vehicle-based measures are embedded into the vehicle and its systems, making them unobtrusive to the driver. These measures include monitoring of the drivers steering patterns for signs of declining alertness and lapses in wakefulness which contribute to road accidents.

Drowsy and fatigued driving is a significant problem. It is responsible for about 1200 deaths and 76,000 injuries every year in the United States alone [1] and the annual numbers worldwide are even higher. Greater than 14% of respondents who polled in Ontario Canada admitted having fallen asleep or nodded off while driving [2]. Sleep-deprived individuals become undetected drowsy drivers on the roads and highways [3]. The other types of drowsy drivers are those who initially received sufficient sleep but engaged in prolonged driving which caused their awareness to deteriorate over time [4]. Prolonged wakefulness is just as dangerous to driver safety as alcohol intoxication [5].

Physiological measures of drowsiness including EEG are not a practical measure of drowsiness due to the complexity of setup and the non-portability of equipment. Commuters would be unable or unwilling to prepare and apply EEG to themselves daily. In addition research has shown that engine vibrations affect EEG outcomes [6].

Eyelid closures are behaviors that can be observed for drowsiness detection. Eye closures which last for more than half a second are especially indicative of sleepiness [7]. PERcentage of eye CLOSure (PERCLOS) refers to the percent of time that a driver's eyelids are closed over a given interval. It has shown good promise as a means for drowsiness detection [8]. Video-based eye closure monitoring methods are ineffective if the driver is wearing eyeglasses [9] and give false positive readings if the driver looks down and around him [10]. Electrooculography (EOG) methods for PERCLOS are too intrusive for widespread daily use due to their use of electrodes and wires.

An important vehicle-based method for determining drowsy driving is the monitoring of a driver's Steering Wheel Movements (SWM) for drowsy patterns. The relationship between SWM and driver drowsiness has been well documented. The correlation between a driver's intervals of steering adjustments and their level of drowsiness has been consistently seen by researchers [11] [12]. Drivers make fewer regular maneuvers when drowsy than when alert. Despite the decline in overall steering inputs, the fewer inputs made are sudden and larger in degree [13] [14]. Steering inputs in fatigued drivers are shown to have fewer micro corrections and more macro-corrections, with sleeping drivers making no corrections [13]-[15]. It has been demonstrated that as the majority of sampled drivers become drowsy, they tend to increasingly trend towards faster and larger steering corrections [13].

With the knowledge that SWM is a highly effective and highly accurate measure of drowsy driving, there have been several methods used by researchers to monitor SWM. Sayed and Eskandarian [16] measured SWM using built-in equipment found in complex vehicle simulators. This approach is cost-prohibitive to the average user and excessively powered for users requiring only SWM monitoring without extra options. Thiffault and Bergeron [13] placed potentiometers along the axis of the steering column to directly measure the turn angle. This would require users to have the technical knowledge and dexterity to install a potentiometer into the steering column of their vehicle or vehicle simulator. Potentiometer use would also require the dismantling of the current vehicle setup to install the potentiometer. Despite the numerous progresses made by researchers towards an effective method of deploying the SWM method on a wide scale, the use of a gyroscope has not been explored despite its ubiquitous use as the standard for rotational measurements in ships, airplanes, submarines and space-crafts. Despite the large amounts of linear vibrations, noise, jolts and accelerations in the gyroscopes routine applications, it remains a highly accurate and widely proliferated standard of rotation measurement. Even though gyroscopes are highly proliferated measures of rotation, their positional measurements have a tendency to drift with time [17]. Luinge [17] used gyroscopes to measure human orientation. To address the drift problem, a 3D accelerometer which served as a tilt sensor was used to continuously recalibrate the gyroscope. Lee *et al.* [18] used a gyroscope to estimate the posture of a mobile inverted pendulum. For drift correction in that case, a tilt sensor was fused with the gyroscope. In spaceflight, NASA uses accelerometers to detect and null errors generated in IMU devices. The accelerations caused by the earth are definitely known, and any discrepancies are considered errors. In terrestrial flights, vacuum gyroscope drifts cause errors in directional readings and pilots have to manually recalibrate the readings by hand, referencing a compass. Ring Laser Gyroscopes (RLGs) are less prone to drift, but they cost upwards of $300,000 for a tri-axial unit [19]. Greene [19] proposed the use of a piezoelectric gyroscope in place of an RLG. Due to drift, an accelerometer was used to stabilize the gyroscopes. In our case, the use of regular automatic recalibration from an accelerometer would ensure seamless operation.

In this study, an Inertial Measurement Unit (IMU) based approach for monitoring the SWM is proposed. IMU devices include gyroscopes and accelerometers. Due to modern Micro Electro Mechanical (MEMS) technologies, gyroscopes and accelerometers are now very affordable to obtain and have very compact form factors. They are no longer restricted by cost or complexity to advanced navigation devices. The proposed use of gyroscopes for SWM monitoring requires a minimal setup that is easy to install and uninstall. The only requirement is that the gyroscope should be affixed to a surface of the steering wheel that would allow the device to be perpendicular to the steering column axis.

An earlier study conducted showed the high accuracy and efficacy of using an accelerometer for the monitoring of drowsiness via SWM methods [20]. The method proposed in this study depends upon the accurate accelerometer-based method from the earlier study for solving the gyroscopes drift problems. In low noise or simulator based environments, the accelerometer-based method might be adequate or preferable if an experimenter has access to cheaper accelerometers. Although there has come to be widespread use of analog accelerometers, there has since come about the availability of 6-axis digital MEMS sensors which incorporate a gyroscope and an accelerometer in a tiny footprint (4 × 4 × 0.9 mm) such as the one used in this study. The benefit of this newer sensor type is that the combined setup helps to simultaneously improve the accuracy of both the accelerometer and the gyroscope. Because accelerometers are prone to linear vibration noise and gyroscopes are prone to slow drifts, the combination of the two sensors has provided new opportunities for SWM monitoring that were originally not available in discrete analog accelerometers. Further, these opportunities are in a very tiny, unobtrusive, and inexpensive package.

An algorithm was developed in this study for monitoring SWM that utilizes a gyroscope's proficiency in detecting angular velocities. The gyroscope outputs the rate of angular change, and then the proposed algorithm interprets this data into SWM position angles with the assistance of an integrated accelerometer which accounts for drift and is located on the same single-DIEmems.

This solution can meet the unmet problem to curb drowsy driving. Despite the safety efforts of the NHSTA and The Federal Highway Administration (FHWA), drowsy drivers continue to take to the wheel and deaths and injuries continue to yield consistently high annual fatality figures. The knowledge for detecting drowsy driving exists but remains within the positive results of numerous successful driving trials. Manufacturers have found no adequate method to deploy these known techniques. The necessity for a practical and inexpensive means for drowsy driving monitoring is especially pertinent as an effective counter to the high fatality numbers. The proposed method is simple, cost-effective and provides not only for drowsy monitoring on new vehicles, but also allows for retrofitting on older vehicles and current model vehicles which on average continue to be manufactured with no drowsy driving detection mechanisms.

Section 2 describes the method and materials for using a gyroscope-accelerometer fusion for SWM detection, Section 3 describes the various tests performed to evaluate the efficacy of the method, Section 4 lists the results obtained from the design and testing of the method, while Sections 5 and 6 discuss the results and list conclusions.

2. Material and Method

2.1. The Basic Concept and Algorithm to Calculate SWM Using a Gyroscope-Accelerometer Fusion

Gyroscopes detect angular velocity and they can be used to derive information about the angular orientation of the steering wheel. An equation for real time monitoring of the rotational position of a gyroscope is given by

[21]:

$$\theta_{gyro}[n] = \theta_{gyro}[n-1] + \Delta n\dot{\theta}[n] \tag{1}$$

where the gyroscope positional angle $\theta_{gyro}[n]$ is based upon knowledge of the last positional sample $\theta_{gyro}[n-1]$ as well as knowledge of the angular displacement since the last sample, which is the product of the rate of angular change $\dot{\theta}[n]$, and the sample interval, Δn. The new position of gyroscope orientation can be determined as $\theta_{gyro}[n]$ with the above Equation (1). The equation was designed especially for capturing rota tional movements originating from human motion [21]. SWM is a product of human motion, and will be served well by this method.

A drawback to using gyroscopes for detection of angular rotation is the tendency for gyroscope positional values to drift [17] [21].

The second part of the proposed IMU device is the accelerometer. An equation for extracting SWM angle solely via an accelerometer is given as [20]:

$$\hat{\theta}[n] = atan\left(\frac{\boldsymbol{A}_x[n]}{\boldsymbol{A}_y[n]}\right) \tag{2}$$

where $\hat{\theta}$ was the SWM angle being estimated from the accelerometer readings of $\boldsymbol{A}_x[n]$ and $\boldsymbol{A}_y[n]$, $\hat{\theta}[n]$ had a strong positive correlation with the steering wheels SWM angle $\theta_w[n]$ [20].

The addition of an accelerometer to the gyroscope compensated for gyroscope drift via the accelerometers perpetual ability for gravitational alignment. This is predicated upon the fact that the operation of Equation (2) depends upon relative readings of gravity on the accelerometers separate axes. The accelerometers tendency to pick up linear vibrations was in turn countered by the gyroscope which has sensitivity to angular velocity. The IMU fusion led to a highly effective combination. When the steering wheel was in a neutral position as shown in **Figure 1**, the main sensor was fastened to the steering wheel surface such the accelerometer gave a neutral angular reading of $\hat{\theta}[n] = 0^\circ$ and the gyroscope Z-axis (g_z marked as "x" was parallel to the steering column axis.

Combining Equations (1) and (2), a complimentary filter was designed to maximize the strengths of both IMU devices. An ideal relationship between θ_{final} and $\hat{\theta}$ which would be easy to update in real time was found to be the causal system:

$$\theta_{\text{final}}[n] = \left(\theta_{\text{final}}[n-1] + \left(\frac{\Delta n\dot{\theta}[n] + \Delta n\dot{\theta}[n-1]}{2}\right)\right) \times \beta_{gyro} + atan\left(\frac{\boldsymbol{A}_x[n]}{\boldsymbol{A}_y[n]}\right) \times \beta_{accel} \tag{3}$$

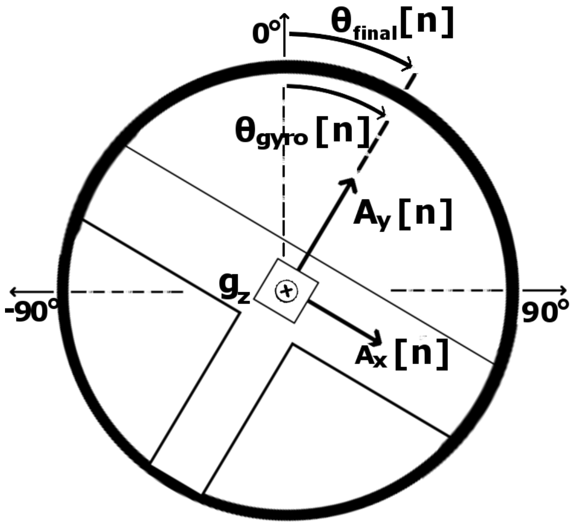


Figure 1. The mapping of the IMU device to the steering wheel.

which is effectively a weighted addition of Equation (1) and Equation (2) with a few slight modifications. The first modification was that $\theta_{gyro}[n]$ took over the role of $\theta_{\text{final}}[n]$. This consequentially resulted in the causal system referencing $\theta_{\text{final}}[n-1]$ rather than $\theta_{gyro}[n-1]$, which is incidentally more correct for the newly formed system in terms of accurately calculating angle based in part upon the last known position. The second difference was that the angular velocity output of the gyroscope was averaged over current and last known reading. This was intended to provide a smoother reading and to improve overall accuracy rates of the newly fused system. At 250 Hz of sampling frequency, which yields 250 samples each second, the averaging of only 2 samples will not adversely affect the overall signal even in the very short term.

Finally, β_{gyro} and β_{accel} were chosen as the coefficients for determining the percentage contribution of each element in Equation (3) to the overall IMU fusion reading of SWM. The summation case therefore must always hold that:

$$\beta_{gyro} + \beta_{accel} = 1 \tag{4}$$

The full process for determination of the coefficient weights for Equation (3) is described in Section 3.

For comparison against current potentiometer based SWM angle recordings, a linear potentiometer in series with the steering axis was used as a reference. Linear potentiometer output voltages vary in linear proportion to their angle of rotation and can be modelled as a standard linear equation:

$$\theta_w = m \times V_p + b \tag{5}$$

where θ_w was the steering wheel angle of rotation in degrees (˚) and V_p was the potentiometer voltage in volts (V). m was the slope of the linear relationship and b was the *y*-intercept of the linear relationship.

To customize our model, the parameters m and V_p were generated by sampling 90 data points per quadrant of the steering wheel, yielding approximately 1 sample of V_p per 1˚. Using these data points to generate a linear relationship gave values of $m = -93.409\ {}^\circ/\text{V}$ and $b = 177.400^\circ$. All further potentiometer readings of SWM angle were calculated by using these parameters with Equation (5) for derivation of θ_w.

2.2. Equipment

The steering wheel used for simulator tasks was the Top Drive GT (Logic3, Hertfordshire, England). Simulator driving tasks were performed using the OpenDS driving simulation software.

An MPU-6050 (InvenSense, San Jose, California) which is a 6-axis combined MEMS gyroscope + accelerometer was the main sensor. The sensitivity of the gyroscope was set at ±250˚·s^{-1} while the sensitivity of the accelerometer was set at ±2 g. At 4 mm × 4 mm × 0.9 mm and weighing less than a gram, the sensor lends itself to portability and non-intrusiveness in any SWM application

The IMU data was collected using an amplifier based on the TI-ADS1299 Analog Front-End (Texas Instruments, Dallas, TX). All data were sampled at 250 Hz.

Data were analyzed with MATLAB. For statistical analysis, linear correlations between data were determined through linear regression, Pearson's Linear Correlation coefficients, and Spearman's Rho. P-values were recorded at $\alpha = 0.05$ unless otherwise specified. The correlations between potentiometer measured SWM and SWM estimated via the gyroscope-accelerometer algorithm were determined using the cross correlation (xcorr) function of the MATLAB signal processing toolbox.

3. Testing

3.1. Test for Applicability of SWM Monitoring with an Accelerometer as the Sole IMU Input

For this test, Equation (3) was used for generating the SWM signal $\theta_{\text{final}}[n]$. However, the signal here was generated using IMU data collected from the accelerometer only during road tests. For this purpose, β_{gyro} was set to 0. The resulting signal was compared against potentiometer readings during the same period to determine the usability of the signal and its correctness.

3.2. Test for Applicability of SWM Monitoring with a Gyroscope as the Sole IMU

Similar to the previous test, Equation (3) was used for generating the SWM signal $\theta_{\text{final}}[n]$ using IMU data collected from the gyroscope during road tests. In this case, β_{accel} was set to 0. The resulting signal was compared against potentiometer readings during the same period to determine the usability of the signal and its correctness.

3.3 Test for Equal Weighting of Gyroscope: Accelerometer Coefficients β_{gyro}:β_{accel}

This test was intended to implement true signal combinations as described by Equation (3). Accelerometer and gyroscope input were initially combined at a ratio of 50:50 for β_{gyro}:β_{accel}.

3.4. Test to Determine Optimal Weights for Gyroscope: Accelerometer Coefficients β_{gyro}:β_{accel}

Combining the two inertial measures of SWM measurements into a single efficient unit required the optimal weight distribution of each component. It was intended that the shock resistant gyroscope which was sensitive to angular rotations inherent to steering behavior and less sensitive to linear or translational noise would provide the bulk of SWM monitoring data. It was also intended that the drift resistant accelerometer would contribute just enough orientation data to ensure that the gyroscope measurement was perpetually calibrated against gravity so that the angle did not drift with time.

Road tests on the high way were useful for making a determination of what ratio of β_{gyro}:β_{accel} was most effective. The aim was to decide which weight ratio yielded the best data in relation to the potentiometer, since the method was to eventually be an efficient replacement of the potentiometer for steering behavior monitoring.

3.5. Test for Accuracy of SWM Readings against Linear Potentiometer Using Selected Weights

After the setup from 2.2 had been used to establish a relationship between θ_{gyro}, θ_{final}, and $\hat{\theta}$, as well as a standard for θ_w, a participant was recruited to perform driving simulator activities for 45 minutes. The correlation between θ_{final} and θ_w over this prolonged period was calculated.

Once strong correlation was seen in a simulator environment, an actual road test was performed which involved the physical mounting of the simulator's steering wheel platform into the vehicle interior while driving tasks were performed by a passenger. This test involved about 20 minutes of driving tasks involving high speed highway driving and city driving in stop-and-go traffic.

4. Results

Data were analyzed using MATLAB. Correlations between the inertial unit's SWM data and the potentiometers SWM data were determined via Pearson's Linear Correlation coefficients, Spearman's Rho, and Kendall's tau. Signal cross correlation between the Inertial Measurement Units output signal and the potentiometers output signal were determined through the xcorr function of the MATLAB signal processing toolbox. P-values were recorded at $\alpha < 0.05$.

4.1. SWM Monitoring with an Accelerometer as the Sole IMU

For this test, Equation (3) was used to generate the SWM signal $\theta_{\text{final}}[n]$ from IMU data collected from the accelerometer during road tests. In this case, β_{gyro} was set to 0.

The purely accelerometer signal demonstrated noticeable amounts of road noise during road tests (**Figure 2(a)**). Although a low pass filter conveniently removed the noise (**Figure 2(b)**), the use of gyroscope fusion demonstrated better results when optimal weighting eliminated the need for hardware or software filtering (Section 4.4). **Table 1** shows the results obtained when each IMU device was used as the sole SWM input. **Table 1** also shows the result of a 50:50 IMU device input ratio.

4.2. SWM Monitoring Using a Gyroscope as the Sole IMU Input

The SWM signal $\theta_{\text{final}}[n]$ was generated from IMU data collected solely from the gyroscope during road tests. In this case, β_{accel} was set to 0. **Figure 2(c)** shows a 24 second section of the gyroscope output waveform after about 10 minutes of road driving. While the gyroscope output was of the correct waveform to match the potentiometer output, the drifting caused the signal to eventually center around 150˚ (**Figure 2(c)**) whereas it would

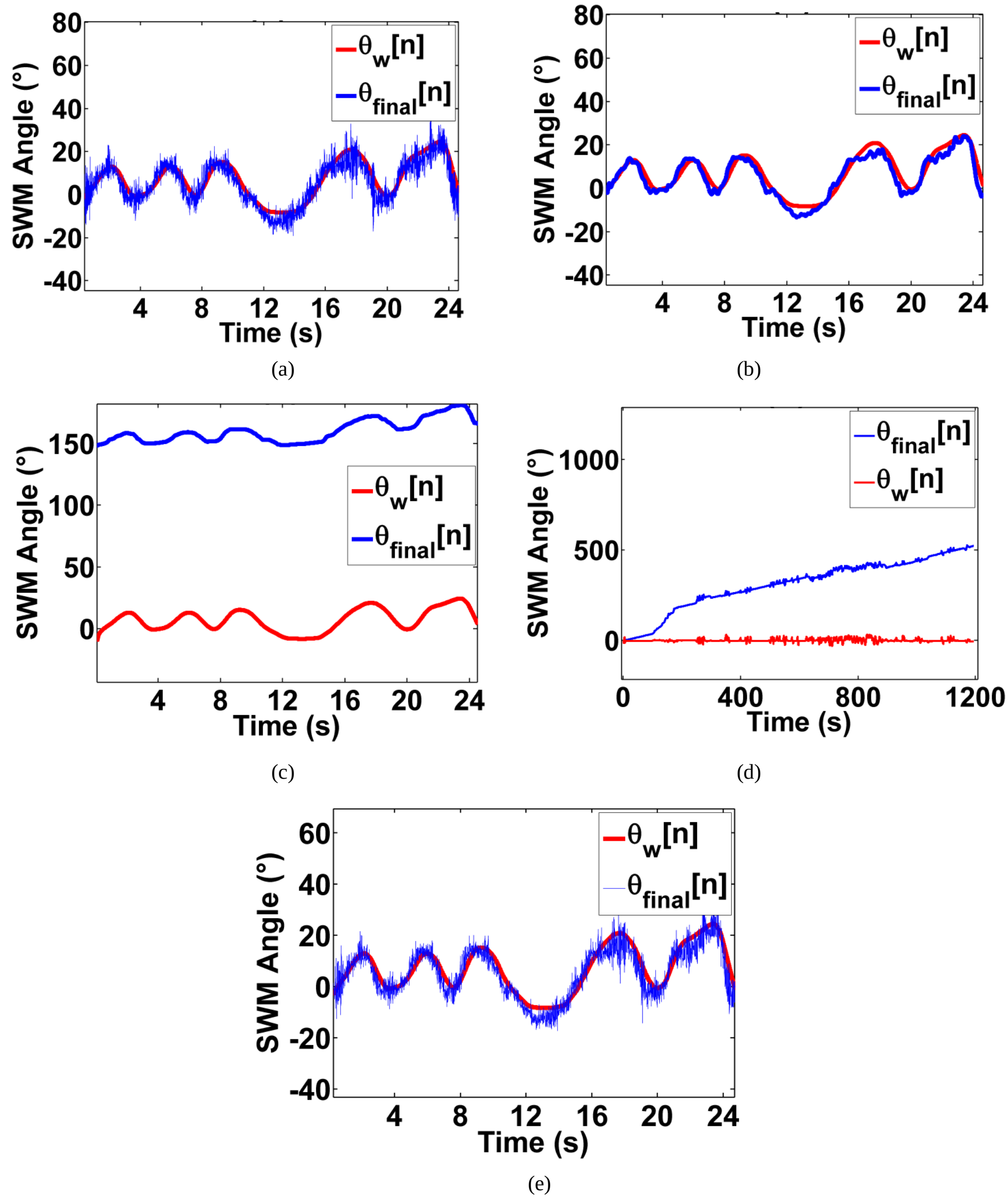


Figure 2. (a) Accelerometer only SWM signal; (b) Accelerometer only SWM signal passed through a 4th order low pass Butterworth filter; (c) Gyroscope only signal demonstrating slow drift; (d) Gyroscope only signal from road test demonstrating how the gyroscope signal would wander into a slow drift in the longer term; (e) A 50:50 distribution of accelerometer: gyroscope signals.

Table 1. Various IMU device ratios and their correlation to potentiometer.

	Ratio	Correlation to potentiometer results			
	β_{accel}:β_{gyro}	Xcorr	Spearman's	Pearson's	Kendall's
a	100:0	0.91	0.88	0.89	0.70
b	100:0 (5Hz low-pass)	0.96	0.95	0.96	0.80
c & d	0:100 (high gyro drift)	0.63	0.85	0.85	0.69
e	50:50	0.93	0.90	0.91	0.73

always be centered at 0˚ when calibrated by the accelerometer complement.

4.3. SWM Monitoring Using Equal Weighting of Gyroscope and Accelerometer Inputs

This test was intended to implement true signal combinations as described by Equation (3). Accelerometer and gyroscope input were initially combined at a ratio of 50:50 for β_{gyro}:β_{accel}. The signal generated from this ratio yielded a fairly noisy signal (**Figure 2(d)**). However, the signal generated through this weighting was less noisy than the signal generated by the accelerometer only.

4.4. Optimal Weights Discovery for Gyroscope: Accelerometer Coefficients β_{gyro}:β_{accel}

Data used to optimize the weight ratio were collected during actual road driving to ensure a robust selection. Various ratios were tried during this analysis and a few of the important ratios are shown in **Table 2**.

The ratio which was finally chosen was 99:1 or $\beta_{gyro} = 0.99$, $\beta_{accel} = 0.01$ (**Figure 2(c)**) because it had a stronger correlation to potentiometer readings in all measures of correlation used, indicating signal correctness. Additionally, visual inspection revealed a good balance between noise reduction properties and better signal agreement with potentiometer readings.

SWM readings from cases in which the β_{gyro}:β_{accel} ratio favored the accelerometer tended towards introducing linear vibrations. These are very easily removable using a low pass filter or an averaging filter. However, using the selected weight ratio of 99:1 as in this case, the accelerometer and gyroscope fusion yielded data that was not significantly affected by linear noises or vibrations, even during highway driving, and city driving on rough roads. It was unnecessary to filter the data. The gyroscope's design as a measure of angular velocity about clearly defined axes contributed greatly to the efficacy of this method for low-noise SWM monitoring. SWM readings from cases in which the β_{gyro}:β_{accel} ratio heavily favored the gyroscope tended towards introducing slow signal drift, while SWM readings from cases in which the β_{gyro}:β_{accel} ratio heavily favored the accelerometer tended towards introducing artifacts (**Figure 2(a)**). The selected ratio yielded optimal results.

4.5. Accuracy of SWM Readings as Compared to the Potentiometer

When subjected to prolonged SWM inputs over a 45 minute driving task, a strong cross correlation between the two signals θ_{final} and θ_w was discovered (xcorr: 0.99; R^2: 0.96; P = 0; Pearson: 0.99; P < 0.05).

As an extension of this test, the SWM readings derived from s θ_{final} data were found to be capable of keeping up with even the most rapid steering wheel movements that were tested. The steering wheel was subjected to greater than 20 sudden rotations at rates up to 150˚s^{-1} and the results during high speed rotations yielded a high signal cross correlation between θ_w and θ_{final} (xcorr: 0.98; P < 0.05; Pearson: 0.97; P < 0.05). A small section of this test is shown in **Figure 4(a)**. The MPU-6050 sensor has a range of up to ±2000˚s^{-1} and was configured in this test for use up to ±250˚·s^{-1}.

To plot **Figure 4** shown below, Equation (4) was used to convert the potentiometer voltages recorded from its amplifier channel directly into θ_w. Over the same sample period, Equation (3) was used to convert readings collected from the gyroscope and accelerometer channels directly into θ_{final}. θ_w and θ_{final} were then overlaid in the resulting plots.

The road test using the simulator steering wheel showed very positive results for the proposed method. The signal θ_{final} was highly correlated to the potentiometer output θ_w (xcorr: 0.992; Pearson: 0.988, P = 0; R^2: 0.976, P

Table 2. Various IMU device ratios and their correlation to potentiometer.

	Ratio	Correlation to potentiometer results			
	β_{accel}:β_{gyro}	XCorr		β_{accel}:β_{gyro}	XCorr
a	10:90	0.92	0.89	0.89	0.71
b	90:10	0.97	0.96	0.95	0.81
c	**99:1**	**0.98**	**0.97**	**0.98**	**0.88**
d	99.5:0.5	0.94	0.90	0.90	0.73

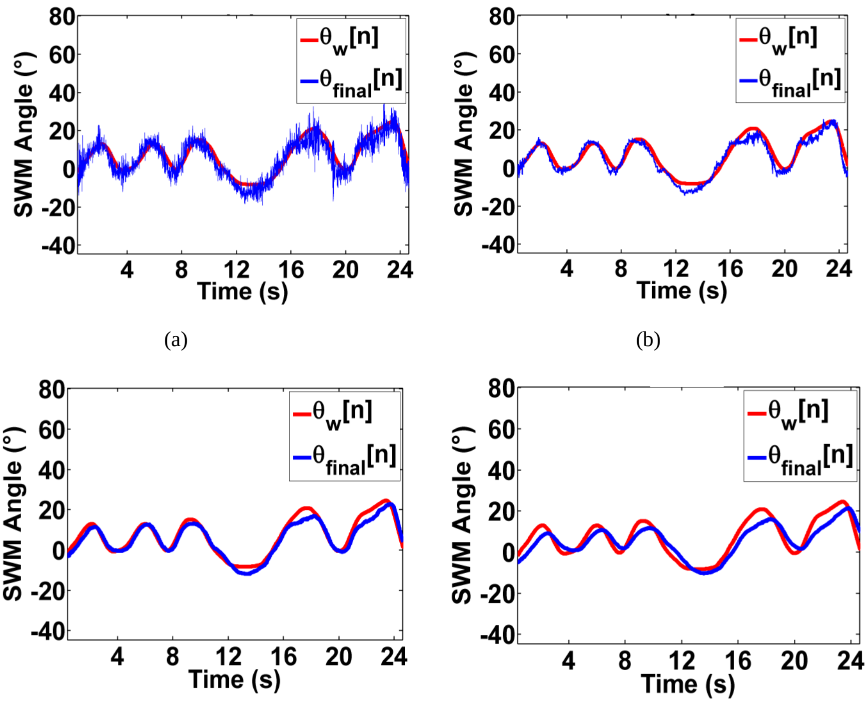
= 0) and the signals overlapped each other for the majority of the recorded time (**Figure 3(b)**).

5. Discussion

The method was tested for efficacy during real road driving. The described method allows for an inexpensive, non-intrusive, and very easy to implement drowsiness detection system without the requirement for complex equipment or major modifications to the current steering system. Although some minor vibrations were seen during the mounting of the device in road tests, these vibrations affected angular signal at less than 0.1˚ angular displacement when unfiltered. However it is important to know that SWM assessment of driver drowsiness is a vehicle based behavioral measure which relies upon detection of trends slowly increasing towards drowsiness and not necessarily upon precision within 0.1˚. Further assessments of the method through the creation of a mobile phone application were able to utilize the mobile devices internal gyroscope and accelerometer for accurate SWM monitoring for drowsiness detection.

β_{gyro} was eventually chosen to be 0.99 and β_{accel} was chosen as 0.01. The output θ_{final} was the positional angle result of the combined IMU setup in degrees. This output indicated the current wheel orientation in units of degrees (˚). The shock resistant gyroscope provided most of the SWM monitoring while the drift resistant accelerometer contributed only the minimum amount of orientation data to ensure that the gyroscope measurement was perpetually calibrated against gravity and did not drift with time.

These findings are important because the method does not require extensive modifications to existing vehicle setups. The high affordability of this primarily gyroscope-based method also improves the feasibility of wide scale deployment. Many individual researchers and federal regulators have invested large amounts of time and manpower to stem the thousands of highway fatalities and injuries that occur worldwide each year as a result of drowsy driving. Although these efforts have yielded reliable methods such as SWM, which has been touted by researchers and government agencies as a potential lifesaver, there has still been no widespread practical means to apply this method. As a result, the vast majority of highway vehicles continue to operate without drowsy driving detection mechanisms, and thousands of fatalities and injuries continue to occur annually. With this method, the well documented SWM method of drowsy driving detection can be applied to curb highway accidents



(a) (b) (c) (d)

Figure 3. Various ratios of β_{gyro}:β_{accel} plotted for (a) 10:90; (b) 90:10; (c) 99:1; (d) 99.5:0.5.

and deaths with minimal cost to drivers and car manufacturers.

Future work will involve embedding this technology into vehicle steering wheels to further the potential for its eventual integration into vehicular systems. In addition, the development of a steering mount implementation will be researched to provide an easy alternative for drivers whose vehicles do not come with such technologies. Other future work includes the investigation of alternate inertial components by manufacturer to further optimize cost/performance output for the end user.

5.1. Slight Variations between θ_w and θ_{final}

Slight variations existed between θ_w and θ_{final} which could be observed in the high velocity rotation testing performed in 3.5. The θ_{final} signal which comprised mostly of gyroscope data exhibited "ears" at the beginning and end of very sudden turns during periods of high and rapidly changing angular velocities (**Figure 4(a)**). Overall, the θ_{final} readings maintained high accuracy, even during sudden movements. Although such unusually high velocity steering activities are not expected to occur except during the most extreme driving cases, possibly involving road accidents. Despite this, the readings of θ_{final} maintained high accuracy.

5.2. Rotations beyond 360˚

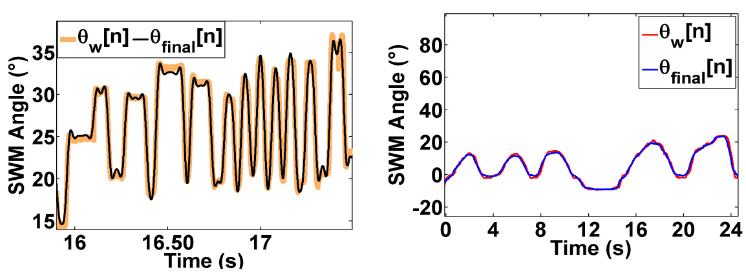
Because most steering wheels rotate through more than 360˚, predictive readings can be used to compensate for this effect. A tiny microcontroller for example can be used to adjust for this. If a range of 361˚ to 720˚ are the base readings of the sensor, any measurements beyond a full counter-clockwise rotation would adaptively read between 0˚ to 360˚ and any measurements beyond a full clockwise rotation would adaptively read between 721˚ to 1080˚.

5.3. Comparison of the Proposed Method with the Earlier Accelerometer-Based Method

The proposed method yielded a more noise resistant method of SWM monitoring when compared to the previous accelerometer-based method [20]. The use of a low pass filter is effective against vehicle and road noises using the previous method, however, if a practical application of SWM monitoring calls for no phase shifting-margin, then the current fusion method might be better suited. Phase shifted signals retain their accurate waveforms, however time delay could occur if filtered improperly. The currently proposed method did not demonstrate any need for filtering, even during real road trials.

The unfiltered accelerometer-based method, while more prone to linear vibration noise than the current method, is very effective in drowsy driving simulation tasks especially as it is dangerous to place sleep deprived subjects on the highway.

The benefit of the currently proposed system is the enhancement of the strengths and weaknesses of two completely different sensors in a method whereby they both work more effectively. The use of a gyroscope for the majority of the SWM data eliminates the problem of linear vibrations due to the gyroscopes insensitivity to such data. It is seen that both methods are effective and accurate for their individually specific tasks. The current method was not prone to road noise, engine noises, and other vehicle noises.



(a) (b)

Figure 4. (a) High speed SWM outputs remained highly accurate representations of ground truth steering movements; (b) The final signal (right) matches the potentiometer signal.

6. Conclusion

This study demonstrated that the effective fusion of a simple gyroscope and accelerometer can be used to accurately monitor SWM for drowsy driving activities including sudden corrections and wide angle corrections. The efficacy of the method was confirmed by comparing the SWM estimates generated by the method with actual SWM readings collected from the steering-wheel potentiometer which yielded high correlation. The high correlation suggests that the method could be used as a direct replacement of other SWM measures for the implementation of SWM-based drowsy detection algorithms.

References

[1] Rau, P. (1996) NHTSA's Drowsy Driver Research Program. National Highway Traffic Safety Administration. Washington DC.

[2] Vanlaar, W., Simpson, H., Mayhew, D. and Robertson, R. (2008) Fatigued and Drowsy Driving: A Survey of Attitudes, Opinions and Behaviors. *Journal of Safety Research*, **39**, 303-309. http://dx.doi.org/10.1016/j.jsr.2007.12.007

[3] Connor, J., Norton, R., Ameratunga, S., Robinson, E., Civil, I., Dunn, R., Bailey, J. and Jackson, R. (2002) Driver Sleepiness and Risk of Serious Injury to Car Occupants: Population Based Case Control Study. *BMJ*, **324**, 1125. http://dx.doi.org/10.1136/bmj.324.7346.1125

[4] Hamblin, P. (1987) Lorry Driver's Time Habits in Work and Their Involvement in Traffic Accidents. *Ergonomics*, **30**, 1323-1333. http://dx.doi.org/10.1080/00140138708966026

[5] Maclean, A.W., Davies, D.R. and Thiele, K. (2003) The Hazards and Prevention of Driving While Sleepy. *Sleep Medicine Reviews*, **7**, 507-521. http://dx.doi.org/10.1016/S1087-0792(03)90004-9

[6] Kim, J.Y., Jeong, C.H., Jung, M.J., Park, J.H. and Jung, D.H. (2013) Highly Reliable Driving Workload Analysis Using Driver Electroencephalogram (EEG) Activities during Driving. *International Journal of Automotive Technology*, **14**, 965-970. http://dx.doi.org/10.1007/s12239-013-0106-z

[7] Ogawa, K. and Shimotani, M. (1997) A Drowsiness Detection system. *Mitsubishi Electric Advance*, **78**, 13-16.

[8] Wierwille, W. (1999) Historical Perspective on Slow Eyelid Closure: Whence PERCLOS? In: *Technical Proceedings of Ocular Measures of Driver Alertness Conference*, Herndon, VA (FHWA Technical Report No. MC-99-136), Federal Highway Administration, Office of Motor Carrier and Highway Safety, Washington DC, 31-53.

[9] Bowman, D.S., Schaudt, W.A. and Hanowski, R.J. (2012) Advances in Drowsy Driver Assistance Systems through Data Fusion. In: *Handbook of Intelligent Vehicles*, Springer, Berlin, 895-912.

[10] Wierwille, W., Hanowski, R., Olson, R., Dinges, D., Price, N., Maislin, G., Powell IV, J., Ecker, A., Mallis, M. and Szuba, M. (2003) NHTSA Drowsy Driver Detection and Interface Project-Final Report. Contract No. DTNH22-D-00-07007, Task Order, 1.

[11] Fukuda, J., Akutsu, E. and Aoki, K. (1995) An Estimation of Driver's Drowsiness Level Using Interval of Steering Adjustment for Lane Keeping. *JSAE Review*, **16**, 197-199. http://dx.doi.org/10.1016/0389-4304(94)00070-A

[12] Elling, M. and Sherman, P. (1994) Evaluation of Steering Wheel Measures for Drowsy Drivers. *Proceedings of the* 27*th ISATA*, Aachen, 31 October-4 November 1994, 207-214.

[13] Thiffault, P. and Bergeron, J. (2003) Monotony of Road Environment and Driver Fatigue: A Simulator Study. *Accident Analysis & Prevention*, **35**, 381-391. http://dx.doi.org/10.1016/S0001-4575(02)00014-3

[14] Eskandarian, A. and Mortazavi, A. (2007) Evaluation of a Smart Algorithm for Commercial Vehicle Driver Drowsiness Detection. *Proceedings of IEEE Conference on Intelligent Vehicles Symposium*, Istanbul, 13-15 June 2007, 553-559.

[15] Yabuta, K., Iizuka, H., Yanagishima, T., Kataoka, Y. and Seno, T. (1985) The Development of Drowsiness Warning Devices. *Proceedings of the* 10*th International Technical Conference on Experimental Safety Vehicles* (*ESV*), *Oxford*, *England*, **10**, 282-288.

[16] Sayed, R. and Eskandarian, A. (2001) Unobtrusive Drowsiness Detection by Neural Network Learning of Driver Steering. *Proceedings of the Institution of Mechanical Engineers*, *Part D*: *Journal of Automobile Engineering*, **215**, 969-975. http://dx.doi.org/10.1243/0954407011528536

[17] Luinge, H., Veltink, P. and Baten, C. (1999) Estimating Orientation with Gyroscopes and Accelerometers. *Technology and Health Care*, **7**, 455-459.

[18] Lee, H., Ryu, S. and Lee, J. (2009) Optimal Posture of Mobile Inverted Pendulum Using a Single Gyroscope and Tilt Sensor. *Proceedings of ICCAS-SICE*, Fukuoka, 18-21 August 2009, 865-870.

[19] Greene, M. (1996) A Solid State Attitude Heading Reference System for General Aviation. *Proceedings of IEEE Con-*

ference on Emerging Technologies and Factory Automation, Kauai, 18-21 November 1996, 413-417.

[20] Lawoyin, S.A., Fei, D.Y. and Bai, O. (2014) Accelerometer-Based Steering Wheel Movement Monitoring for Drowsy Driving Detection. *Proceedings of the Institution of Mechanical Engineers, Part D*: *Journal of Automobile Engineering*, Published Online 31 October 2014. http://dx.doi.org/10.1177/0954407014536148

[21] Sakaguchi, T., Kanamori, T. and Katayose, H. (1996) Human Motion Capture by Integrating Gyroscopes and Accelerometers. *Proceedings of IEEE/SICE/RSJ International Conference on Multisensor Fusion and Integration for Intelligent Systems*, Washington DC, 8-11 December 1996, 470-475.

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Skin Problems among Users of the Urine-Based Fertiliser in Ouagadougou Periurban Areas, Burkina Faso: A Prospective Study

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Abstract

The great challenge for the sustainable use of excreta (urine, faeces) in agriculture is to increase the benefits of these products as resources and decrease the negative effects on human health. The risk of gastrointestinal diseases associated with the use of human excreta as natural fertilisers is well established, while information on skin problems remains largely anecdotal. The objective of this study was to evaluate the prevalence of skin problems among people involved in the handling of the urine used as fertiliser along a productive sanitation system in Ouagadougou periurban areas. A questionnaire was used for each targeted worker to collect data on sociodemographic characteristics, conditions of work and reported health symptoms such as skin burning, itching, eye irritation and paronychia. The exposure measurements were essentially based on field observations. A total of 435 people were interviewed, including 45 workers in urine storage sites, 209 farmers using urine-based fertiliser and 181 control farmers. More than 35% of site workers reported skin symptoms. For farmers using urine-based fertiliser and their controls, 17.2% and 26.0% reported skin symptoms, respectively. Overall, the associations between skin symptoms and the handling of urine used as fertiliser were almost significant ($P < 0.06$). Also, the study showed that these skin symptoms reported by the urine handlers are associated with conditions

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of work. Effective preventive measures such as wearing suitable protective equipment and practicing good personal hygiene should be emphasized. This topic needs to be further examined using longitudinal studies.

Keywords

Human Urine, Fertiliser, Exposure, Hazardous Agents, Skin Problems

1. Introduction

In order to decrease reliance on chemical fertilisers, human excreta (urine, faeces) are used in agriculture around the world [1]-[3]. In Burkina Faso, urine-based fertiliser was used firstly by truck farmers in Ouagadougou periurban areas, along productive sanitation systems [4]. The main steps in the management of a sanitation system are: urine collection from the eco-toilets (Urine Diversion Dry Toilet), transportation and storage (on a site) before the use as liquid fertiliser. The quality of the urine from these systems was previously evaluated [3] [4].

Human health risks associated with the use of wastewater and excreta in agriculture have been well shown [5]. Although the risk for certain gastrointestinal diseases has been established, the information on other potential human health risks is still largely anecdotal. Studies in many countries with farmers using wastewater suggested a high prevalence of the skin ailments [6]-[8]. In general, causes of these skin problems remained unknown [8] [9].

Also, farmers and workers involved in handling activities (e.g. cleaners) often complain about skin problems caused by various irritants and allergens, including sun [10], biological agents such as bacteria [11] [12] and chemicals such as pesticides and heavy metals [13]-[15]. Some soaps and detergents can damage the skin [16] [17].

The skin is a considerable interface between man and his environment [18]; it is an important portal of entry for hazardous agents and a vulnerable target tissue as well [19] [20]. Colonized by a normal resident flora, the skin is frequently contaminated by pathogens. Staphylococci and enterococci are the most common skin bacterial contaminants [12] [21] [22]. About 20% of the normal population carries continuously *Staphylococcus aureus* on the body. This chronic carriage is a risk factor for skin infections [23] [24]. Paronychia a skin infection of the fingers, occurs especially among manual workers. Staphylococci are the main causative agents, but can also be an Enterococcus or gram-negative bacteria [21].

In Burkina Faso, the incidence of skin diseases associated with exposure to wastewater and agricultural inputs (fertilisers and pesticides) is not known. This incidence is probably high for the following reasons: 1) The presence in irrigated water of some hazardous agents [25]-[27]; 2) The large amounts of chemical inputs frequently handled by farmworkers; 3) The use of prohibited pesticides in the agricultural sector [27]; and 4) The non-compliance with protective measures on handling some products in the fields [28].

Ammonia is used to produce chemical fertilisers. It also helps to preserve stored fruits [29]. However, this gas can cause severe skin irritation or burns due to its high solubility in water. Therefore, skin irritation can occur after sweating if the skin is in contact with ammonia, because of ammonia's caustic effect [29] [30]. Irritation due to ammonia can also affect eyes, causing watering and conjunctival ulceration. Glaucoma can occur after a long-term exposure to ammonia [29] [31].

This study was conducted among handlers of the urine used as fertiliser in Ouagadougou periurban areas, Burkina Faso. The main objective was to evaluate the prevalence of skin problems reported by people involved in the urine handling along a productive sanitation system.

2. Materials and Methods

2.1. Research Setting

The study was conducted in Ouagadougou periurban areas, where a large scale project in productive sanitation was implemented. For a period of three years (2006-2009), the project has equipped around 1000 households with eco-toilets (Urine Diversion Dry Toilets, UDDT). In each sector covered by the project, a productive sanitation system was set up, in which excreta is collected separately via UDDT and are transported and stored on a site before the use as fertilisers in the field. Urine was stored in jerry cans (20 L) and tanks (1000 L).

Each filled container was closed for at least 30 days. On average, 600 jerry cans and 15 tanks per site were used to manage the urine stocks. Our study was limited to two sites and conducted for a period of 11 months (February 2011-January 2012). Parameters of interest (pH, ammonia, heavy metals, *E. coli*, *S. aureus*, *Enterococcus sp*.) in urine from the studied sanitation system have been previously measured [3].

2.2. Study Population

Two groups of workers along productive sanitation systems were targeted: 1) Handlers of the urine in storage sites, in which the main tasks were collection and transportation of the urine from households to storage sites, and the decanting, cleaning and maintenance of containers; and 2) Farmers using urine-based fertiliser. A control group was integrated in this study, including non-urine using farmers, working in the same conditions as the others. All participants in this study were volunteers.

2.3. Data Collection

The survey on skin problems among targeted groups was preceded by the field visits in order to report the work conditions of people. To do this, forms were filled out at each visit, indicating observations concerning the hygiene practices in urine storage sites, the quality of irrigation water, and the protective measures taken during the urine handling. Data from field visits guided us to formulate relevant items for a questionnaire, which were individually administered at the workplace. The interviews were conducted face-to-face with investigators. The questionnaire was comprised of three parts: 1) The first part consists of items to collect sociodemographic characteristics of respondents; 2) The second part includes items relating to the environment and work conditions. These are the questions to find out what activities the person did, frequency of the urine handling, and about protective equipment used when working; and 3) The third part, which includes items relating to recent and/or current skin problems self-reported for the duration of work. Skin burning, itching, eye irritation and paronychia were the health symptoms examined. The location of these symptoms was also required to respondents.

2.4. Data Analysis

Statistical analysis of data was performed using the STATA V12.1 (Stata Corp 4905 Lakeway Drive, Texas, USA) software. The variables were analyzed by Chi-square test or Fisher's exact test. A *P*-value less than 0.05 was considered statistically significant.

3. Results

3.1. Description of the Study Population

In total, 435 people responded to the questionnaire, including forty-five (45) site urine handlers, two hundred and nine (209) farmers using urine-based fertiliser and one hundred eighty-one (181) as control farmers. The sociodemographic characteristics of the respondents are presented in **Table 1**.

The average age of respondents was about 38 years. Male interviews predominated, with 60% and 80% for site workers and farmers respectively. The majority of those interviewed people had a low level of education (primary or uneducated). Among field workers, truck farmers were the most numerous (97%), followed by flower growers (3%). For the duration of work, 53% of site urine handlers had more than 3 years and 20% had one year or less. About 87% of farmers had more than 3 years in working.

3.2. Skin Problems among Targeted Groups

More than 35% of site urine handlers have reported skin symptoms (**Table 2**), including skin burning (8.8%), itching (22.2%) and eye irritation (4.4%). No case of paronychia has been reported. Overall, the association between reported skin symptoms and the handling of urine on storage site was significant ($P < 0.05$).

In farmers, handling and non handling (control) the urine, the percentage of reported skin symptoms were 17.2% and 26.0% respectively (**Table 2**). These health symptoms reported by farmers handling the urine and their controls included, skin burning (4.8% vs. 7.7%), itching (6.7% vs. 4.4%) and paronychia (5.7% vs. 13.8%).

Table 1. Main sociodemographic characteristics of all respondents.

Personal characteristics	Site urine handlers n = 45	Urine handling farmers n = 209	Control farmers n = 181
Age (year)			
Mean[δ] (SD)	37.1 (12.6)	39.9 (9.0)	38.6 (11.9)
Age groups			
<21 n (%)	5 (11.1)	7 (3.3)	22 (12.1)
21 - 49 n (%)	30 (66.6)	163 (77.9)	115 (63.5)
>49 n (%)	10 (22.2)	39 (18.6)	44 (24.3)
Sex			
Male n (%)	27 (60)	193 (92.3)	127 (70.1)
Female n (%)	18 (40)	16 (7.6)	54 (29.8)
Educational level			
High school n (%)	0 (0)	1 (0.5)	0 (0)
Secondary school n (%)	10 (22.2)	25 (11.9)	17 (9.4)
Primary school n (%)	20 (44.4)	73 (34.9)	29 (16.0)
Uneducated n (%)	15 (33.3)	110 (52.6)	135 (74.5)
Farming type			
Horticultural n (%)	/	206 (98.5)	173 (95.5)
Ornamental n (%)	/	3 (1.4)	8 (4.5)
Duration of work (year)			
<1 n (%)	9 (20)	6 (2.8)	6 (3.3)
1 - 3 n (%)	12 (26.6)	11 (5.3)	25 (13.8)
>3 n (%)	24 (53.3)	192 (91.8)	150 (82.8)

[δ]Values given as mean (SD).

Table 2. Percentage of skin problems reported by respondents.

Symptoms	Site urine handlers n = 45	Urine handling farmers n = 209	Control farmers n = 181
	n (%)	n (%)	n (%)
Overall	16 (35.5)	36 (17.2)	47 (26.0)
Burning	4 (8.8)	10 (4.8)	14 (7.7)
Itching	10 (22.2)	14 (6.7)	8 (4.4)
Paronychia	0 (0)	12 (5.7)	25 (13.8)
Eye irritation	2 (4.4)	0 (0)	0 (0)

3.3. Occurrence of Skin Symptoms and Work Conditions

In **Table 3**, it is shown the incidence rates of skin symptoms related to work conditions in handlers of the urine on storage site. Sixteen (16) workers (n = 45) reported skin problems "due to the urine exposure". In less than one year in working, 50% and 30% of them respectively had complained about skin burning and itching. Those who reported eye irritation had more than 3 years in the work.

Table 3. Incidence rate of skin symptoms reported by site urine handlers.

Variables	Skin burning	Itching	Eye irritation
	%	%	%
Duration of work (year)†			
<1	50	30	0
1 - 3	25	40	0
>3	25	30	100
Frequency in urine handling†			
≥Twice per week	75	60	100
≤Twice per week	25	40	0
Personal protective equipment			
Yes	100	90	100
No	0	10	0
Location of skin symptoms			
Hand	37.5	25	0
Forearm	37.5	50	0
Foot	25	0	0
Other	0	25	100

†$P = 0.06$.

By handling the urine on storage site, with a frequency of more than twice per week, had given incidence rates of 75%, 60% and 100% respectively for skin burning, itching and eye irritation (**Table 3**). Surprisingly, we observed that almost all workers on the urine storage site and who reported skin symptoms had personal protective equipment consisting of a coat with short sleeves, a gas mask, boots and gloves. This data confirms the observations made in the field in that there was a lack of interest in wearing this protective equipment, the poor state and the unsuitability of these protective materials. Skin symptoms mentioned were reported more than once in the concerned site workers. Itching and skin burning were most often located on forearms, hands and feet.

In **Table 4**, the incidence rates of skin symptoms reported by farmers using urine-based fertiliser are presented.

In farmers handling urine-based fertiliser which reported skin symptoms (26 among 209 in total), about 85% had at least two years in the work. For these farmers, the frequency of handling urine averaged once per week. More than half of farmers (59%) did not use a personal protective equipment (**Table 4**). Skin burning and itching were experienced by all reporting farmers (100%). For paronychia, 83.3% of reporting people were truck farmers and 16.7%, flower growers. Overall, the skin burning was most often located on hands and feet, while itching occurred on forearms. Except for paronychia, the other skin symptoms were experienced more than once by almost all reporting farmers. Observations in the field have shown that the farmers' existing protective equipment was not worn automatically during the urine handling. The reasons for this disinterest on wearing personal protective equipment have not been clearly given. Also, in the opinion of almost all farmworkers interviewed, "the quality of the water used for irrigation was good, since it was extracted from wells and dams". Taking into account all of these skin symptoms that were reported, the associations found between work factors, particularly the frequency of the urine handling and the duration of work (**Table 3** and **Table 4**) were almost significant ($P = 0.06$).

4. Discussion

In this study, we evaluated the possible links between skin problems and the handling of urine among people

Table 4. Incidence rate of skin symptoms reported by farmers using urine-based fertilizer.

Variables	Skin burning	Itching	Paronychia
	%	%	%
Duration of work (year)†			
<1	10	0	8.3
1 - 3	30	40	25
>3	60	60	66.7
Frequency in urine handling†			
≥Twice per week	0	0	0
≤Twice per week	100	100	100
Personal protective equipment			
Yes	50	29	41.7
No	50	71	58.3
Farming type			
Horticultural	100	100	83.3
Ornamental	0	0	16.7
Location of skin symptoms			
Hand	36.3	35.7	100
Forearm	27.2	50	0
Foot	36.3	14.3	0
Other	0	0	0

†$P = 0.06$.

involved within productive sanitation systems in Ouagadougou periurban areas. The health symptoms examined were essentially skin burning, itching, eye irritation and paronychia, which can be caused by various agents potentially existing in the work environment. Exposure measurements were based mainly on observations made at any moment by the urine handlers on the workplace (storage site and farm field). We also considered as indicators of risk, data from a previous study on the characterization of chemical (pH, ammonia, heavy metals) and bacteriological (*E. coli*, *S. aureus*, *Enterococcus sp*.) parameters in the urine of the studied sanitation system [3].

Overall, the results of this study indicate skin symptoms reported by respondents were associated with the work they do. The prevalence of skin problems in the urine site urine handlers was almost the double of that found in farmers handling urine-based fertiliser (**Table 2**). Yet, according to field observations, the wearing of the personal protective equipment while handling urine was spontaneous among site workers compared to farmers. The handling of the untreated urine (before storage) may have more risk of disease transmission [32]. Based on this assumption, the high prevalence of skin symptoms in handlers of urine on storage sites (compared to farmers) was uncovered. Wearing personal protective equipment did not effectively prevent skin symptoms. This data confirms the observations made at the field regarding protective materials (poor state and unsuitable).

We observed that farmers not handling urine-based fertiliser also reported skin symptoms. Further investigations on the risks faced by farmers in the fields are needed. It is likely that the causes of skin diseases among farmworkers are many. However, some studies suggested that exposure to chemical inputs, e.g. pesticides and fertilisers [14] [33] and irrigation water [8] [34] were the main causes of skin problems self-reported among farmers. Wastewater often used in urban agriculture potentially contains chemical (e.g. heavy metals, pesticide residues) and biological agents (e.g. bacteria, viruses, enzymes) which, in contact with skin can affect it. Farmers interviewed in this study extracted their irrigation water from wells and dams. Regular skin contact with water can have a risk of disease because this irrigated water probably contains chemical and biological contaminants from soil or various releases [25] [27] [35]. However, the wearing of personal protective equipment during the handling of chemical inputs and wastewater could minimize the risk of some skin symptoms.

In addition, we observed significant associations between examined skin symptoms and work conditions, particularly the frequency of the urine handling and the duration of work (**Table 3** and **Table 4**). Our field observations showed that all urine handlers complained of strong smells due to ammonia, while the so-called "gas mask" was worn. We also found that there could be phases in the urine handling that are more at risk than others. For example among site urine handlers, exposure risks are high by transporting and decanting urine. In farm, workers using urine-based fertiliser, mix preparation (dilution) are probably the crucial exposure phase. During these all activities, parts of the body not covered such as face, hands and forearms were in frequent contact with aerosols from urine.

Previous studies have shown that the handling of products with high alkalinity (pH > 12), exposed people to the risk of skin burning [30] [36]. However, pH values of the handled urine by targeted actors were less than 9 [3]; therefore, the alkaline effect of urine on the skin of handlers is probably negligible. Also, the concentrations of chromium, lead, copper, cadmium and nickel in the urine were low [3]. So, the implication of heavy metals effects explaining the skin symptoms experienced by the urine handlers can be excluded, as much as the affected body parts (hands, forearms, eyes) were not directly "dipped" in urine during the handling. Moreover, skin irritation due to ammonia can be considered, because of its high concentration in the handled urine and its possible caustic effect on a sweated skin. Based on the above data, it seems clear that the hot and semi-arid climate favoring excessive sweating can be a worsening factor of ammonia toxicity, that also was confirmed by authors [30].

Other associations found in this study are difficult to explain. This is the case of the connection between the occurrence of a paronychia and exposure to the urine-based fertiliser, in the sense that the causative agent is often carried by the subject himself [12] [21]. In this situation, it is necessary that good hygiene practices, including washing the body after work be maintained to prevent some skin diseases.

Few limits to this study can be mentioned. First, respondents were asked to recall the experienced skin symptoms, since the beginning of their work. It is possible that subjective responses have been provided by the surveyed population. In order to minimize these errors due to oversight, Vallejos and *et al.* [14] asked to farmworkers handling pesticides to recall their skin symptoms reported in the previous seven days before the interview. But, we think that approach to be too limiting the period for recalling health symptoms, potentially hiding some evidence related to exposures. Second, skin problems examined in this study may result from many causes and cannot be solely attributed to the urine exposure. As proof, farmers not handling urine-based fertiliser reported the same skin symptoms that handlers. Third, the method of data collection used do not reflect precise measurements as the severity and the duration of the reported skin symptoms, which are important parameters for assessing effects associated with exposure to hazardous substances. In order to lessen the mentioned limits, we think that conducting longitudinal studies could be necessary, because they analyze in long-term targeted groups. Unfortunately, in the context of the current study, it was difficult to constitute cohorts among the urine handlers since their work was unstable and precarious.

Having a better understanding of factors associated with the occurrence of skin problems can help in efforts to prevent and to treat [14] [37]. Thus, one of the strengths of this study was to provide information on the prevalence of skin symptoms in people exposed to the urine used as fertiliser. The results of this first investigation may call out the people exposed to products possessing a potential health risk (e.g. chemical inputs, excreta-based fertilisers) to reinforce personal protective measures. Wearing a suitable protective equipment including coat with long sleeves, gloves covering forearms, boots and goggles, should certainly reduce the risk of skin symptoms here investigated.

5. Conclusion

This study suggests the existence of associations between health symptoms such as skin burning, itching, eye irritation and the handling of the urine used as fertiliser. The harmful effect of ammonia on the skin seems predominant compared to other measurable parameters in the handled urine. However, skin symptoms examined in this study could not be exclusively attributed to the urine exposure; other factors inherent to the workplace can be implicated. Based on the data obtained, it is necessary that people involved in the handling of the urine used as fertiliser, have to maintain personal good hygiene practices and wear protective equipment while working to reduce the health risks. In order to make our data more incisive and better explore the topic, additional studies are needed. For example, longitudinal studies by monitoring regularly some parameters (e.g. diagnosis, severity and duration of health symptoms) within cohorts, should better assess the effects of ailments due to some exposure. Thus, data from such studies can guide health policy makers, especially in the agricultural sector where the effects associated with exposure to chemical inputs are not well established.

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References

[1] Mnkeni, P.N.S., Kutu, F.R., Muchaonyerwa, P. and Austin, L.M. (2008) Evaluation of Human Urine as a Source of Nutrients for Selected Vegetables and Maize under Tunnel House Conditions in the Eastern Cape, South Africa. *Waste Management & Research*, **26**, 132-139. http://dx.doi.org/10.1177/0734242X07079179

[2] Richert, A., Gensch, R., Jönsson, H., Dagerskog, L., Stenström, T. and Bonzi, M. (2010) Food Security and Productivesanitation: Practical Guideline on the Use of Urine in Crop Production. *Sustainable Sanitation Practice*, **3**, 31-33.

[3] Makaya, J.M., Savadogo, A., Somda, M.K., Bour, J.B., Barro, N. and Traoré, A.S. (2014) Quality of Human Urine Used as Fertilizer: Case of an Ecological Sanitation System in Ouagadougou Peri-Urban Areas—Burkina Faso. *Journal of Environmental Protection*, **5**, 467-474. http://dx.doi.org/10.4236/jep.2014.56049

[4] Dagerskog, L. and Bonzi, M. (2010) Opening Minds and Closing Loops—Productive Sanitation Initiatives in Burkina Faso and Niger. *Sustainable Sanitation Practice*, **3**, 4-11.

[5] World Health Organization (WHO) (2006) Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Vol. 4, Wastewater Use in Agriculture. World Health Organization, Geneva, 196.

[6] Paulsen, E., Skov, P.S. and Andersen, K.E. (1998) Immediate Skin and Mucosal Symptoms from Pot Plants and Vegetables in Gardeners and Greenhouse Workers. *Contact Dermatitis*, **39**, 166-170. http://dx.doi.org/10.1111/j.1600-0536.1998.tb05888.x

[7] Douwes, J., Mannetje, A. and Heederik, D. (2000) Work-Related Symptoms in Sewage Treatment Workers. *Annals of Agricultural and Environmental Medicine*, **8**, 39-45.

[8] Trang, D.T., van der Hoek, W., Tuan, N.D., Cam, P.D., Viet, V.H., Luu, D.D., Konradsen, F. and Dalsgaard, A. (2007) Skin Disease among Farmers Using Wastewater in Rice Cultivation in Nam Dinh, Vietnam. *Tropical Medicine and International Health*, **12**, 51-58. http://dx.doi.org/10.1111/j.1365-3156.2007.01941.x

[9] van der Hoek, W., Anh, V.T., Cam, P.D., Vicheth, C. and Dalsgaard, A. (2005) Skin Diseases among People Using Urban Wastewater in Phnom Penh. *UA Magazine*, **14**, 30-31.

[10] Schenker, M.B., Orenstein, M.R. and Samuels, S.J. (2002) Use of Protective Equipment among California Farmers. *American Journal of Industrial Medicine*, **42**, 455-464. http://dx.doi.org/10.1002/ajim.10134

[11] Mahe, A., Cissé, I.A., Faye, O., N'Diaye, H.T. and Niamba, P. (1998) Skin Diseases in Bamako (Mali). *International Journal of Dermatology*, **37**, 673-676. http://dx.doi.org/10.1046/j.1365-4362.1998.00454.x

[12] Lorette, G., Beaulieu, P.H., Guihard, W., Lemaître, M., Jarlier, N., Bismuth, R., Duru, G. and Janin, N. (2003) Skin Infections in Communities: Bacteria Involved and Sensibility to Antibiotics. *Annales de Dermatologie et de Venereologie*, **130**, 723-731.

[13] Guo, Y.L., Wang, B.J., Lee, C.C. and Wang, J.D. (1996) Prevalence of Dermatoses and Skin Sensitisation Associated with Use of Pesticides in Fruit Farmers of Southern Taiwan. *Occupational Environ Medicine*, **53**, 427-431. http://dx.doi.org/10.1136/oem.53.6.427

[14] Vallejos, Q.M., Schulz, M.R., Quandt, S.A., Feldman, S.R., Galvan, L., Verma, A., Fleischer, A.B., Rapp, S.R. and Arcury, T.A. (2008) Self Report of Skin Problems among Farmworkers in North Carolina. *American Journal of Industrial Medicine*, **51**, 204-212. http://dx.doi.org/10.1002/ajim.20550

[15] Horiuchi, N., Oguchi, S., Nagami, H. and Nishigaki, Y. (2008) Pesticide-Related Dermatitis in Saku Districk, Japan, 1975-2000. *International Journal of Occupational and Environmental Health*, **14**, 25-34. http://dx.doi.org/10.1179/oeh.2008.14.1.25

[16] Pedersen, L.K., Johansen, J.D., Held, E. and Agner, T. (2004) Augmentation of Skin Response by Exposure to a Combination of Allergens and Irritants—A Review. *Contact Dermatitis*, **50**, 265-273.

http://dx.doi.org/10.1111/j.0105-1873.2004.00342.x

[17] Lynde, C.B., Obadia, M., Liss, G.M., Ribeiro, M., Holness, D.L. and Tarlo, S.M. (2009) Cutaneous and Respiratory Symptoms among Professional Cleaners. *Occupational Medicine*, **59**, 249-254. http://dx.doi.org/10.1093/occmed/kqp051

[18] Suskind, R.R. (1977) Environment and the Skin. *Environmental Health Perspectives*, **20**, 27-37. http://dx.doi.org/10.1289/ehp.772027

[19] Thyssen, J.P., Johansen, J.D., Linneberg, A. and Menné, T. (2010) The Epidemiology of Hand Eczema in the General Population-Prevalence and Main Findings. *Contact Dermatitis*, **62**, 75-87. http://dx.doi.org/10.1111/j.1600-0536.2009.01669.x

[20] Smedley, J., Williams, S., Peel, P. and Pedersen, K. (2012) Management of Occupational Dermatitis in Healthcare Workers: A Systematic Review. *Occupational and Environmental Medicine*, **69**, 276-279. http://dx.doi.org/10.1136/oemed-2011-100315

[21] Larson, E.L., Hughe, C.A. and Pyrek, J.D. (1998) Changes in Bacterial Flora Associated with Skin Damage on Hands of Healthcare Personnel. *American Journal of Infection Control*, **26**, 513-521. http://dx.doi.org/10.1016/S0196-6553(98)70025-2

[22] Gong, J.Q., Lin, L. and Lin, T. (2006) Skin Colonization by *Staphylococcus aureus* in Patients with Eczema and Atopic Dermatitis and Relevant Combined Topical Therapy: A Double Blind Multicentre Randomized Controlled Trial. *British Journal of Dermatology*, **155**, 680-687. http://dx.doi.org/10.1111/j.1365-2133.2006.07410.x

[23] Harbarth, S., Liassine, N., Dharan, S., Herrault, P., Auckenthaler, R. and Pittet, D. (2000) Risk Factors for Persistent Carriage of Methicillin-Resistant *Staphylococcus aureus*. *Clinical Infectious Diseases*, **3**, 1380-1385. http://dx.doi.org/10.1086/317484

[24] Wertheim, H.F.L., Melles, D.C., Vos, M.C., van Leeuwen, W., van Belkum, A. and Verbrugh, H.A. (2005) The Role of Nasal Carriage in *Staphylococcus aureus* Infections. *The Lancet Infectious Diseases*, **5**, 751-762. http://dx.doi.org/10.1016/S1473-3099(05)70295-4

[25] Sou, Y.M. (2009) Recycling Wastewater for Irrigation: Fertilizing Potential, Health Risks and Impacts on Soil Quality. Ph.D. Dissertation, EPF Lausanne, Lausanne.

[26] Dianou, D., Savadogo, B., Zongo, D., Zougouri, T., Poda, J.N., Bado, H. and Rosillon, F. (2011) Surface Waters Quality of the Sourou Valley: The Case of Mouhoun, Sourou, Debe and Gana Rivers in Burkina Faso. *International Journal of Biological and Chemical Sciences*, **5**, 1571-1589.

[27] Nitiema, L.W., Savadogo, B., Zongo, D., Kaboré, A., Poda, J.N., Traoré, A.S. and Dianou, D. (2013) Microbial Quality of Wastewater Used in Urban Truck Farming and Health Risks Issues in Developing Countries: Case Study of Ouagadougou in Burkina Faso. *Journal of Environmental Protection*, **4**, 575-584. http://dx.doi.org/10.4236/jep.2013.46067

[28] Bassolé, D. and Ouédraogo, L. (2007) Problem of the Use of Pesticides in Crop Conservation and Truck Farming in Urban and Peri-Urban Areas, Burkina Faso. International Fertilizer Development Center, IFDC, 51 p.

[29] Agency for Toxic Substances and Disease Registry, ATSDR (2004) Toxicological Profiles for Ammonia. US Department of Health and Human Services, Public Health Services, Atlanta. http://www.atsdr.cdc.gov/toxpro2.html

[30] Blanco, L.E., Aragon, A., Lundberg, I. and Lidén, C. (2005) Determinants of Dermal Exposure among Nicaraguan Subsistence Farmers during Pesticide Applications with Backpack Sprayers. *Annals of Occupational Hygiene*, **49**, 17-24.

[31] Beare, J.D., Wilson, R.S. and Marsh, R.J. (1988) Ammonia Burns of the Eye: Old Weapon in New Hands. *British Medicine Journal*, **296**, 590. http://dx.doi.org/10.1136/bmj.296.6622.590

[32] Jönsson, H. and Vinnerås, B. (2007) Experiences and Suggestions for Collection Systems for Source-Separated Urine and Faeces. *Water Science and Technology*, **56**, 71-76. http://dx.doi.org/10.2166/wst.2007.558

[33] Strong, L.L., Thompson, B., Coronado, G.D., Griffith, W.C., Vigoren, E.M. and Islas, I. (2004) Health Symptoms and Exposure to Organophosphate Pesticides in Farmworkers. *American Journal of Industrial Medicine*, **46**, 599-606. http://dx.doi.org/10.1002/ajim.20095

[34] Shrutakirthi, S.D., Suraj, D., Sugandhi, R., Girija, R. and Sreekumaran, N. (2005) Dermatoses among Paddy Field Workers—A Descriptive, Cross-Sectional Pilot Study. *Indian Journal of Dermatology, Venereology and Leprology*, **71**, 254-258. http://dx.doi.org/10.4103/0378-6323.16617

[35] Cissé, G. (1997) Health Impact of Wastewater Utilization in Urban Agriculture: Case of Truck Farming in Ouagadougou. Ph.D. Dissertation, EPF Lausanne, Lausanne.

[36] Géraut, C. and Frimat, P. (1993) Dermatoses in Cement Users. *Archives des Maladies Professionnelles*, **54**, 312-314.

[37] Susitaival, P., Flyvholm, M.A. and Meding, B. (2003) Nordic Occupational Skin Questionnaire (NOSQ-2002): A New Tool for Surveying Occupational Skin Diseases and Exposure. *Contact Dermatitis*, **49**, 70-76. http://dx.doi.org/10.1111/j.0105-1873.2003.00159.x