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Combining statistics from two national complex surveys to estimate injury rates per hour exposed and variance by activity in the USA

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ABSTRACT

Background A common issue in descriptive injury epidemiology is that in order to calculate injury rates that account for the time spent in an activity, both injury cases and exposure time of specific activities need to be collected. In reality, few national surveys have this capacity. To address this issue, we combined statistics from two different national complex surveys as inputs for the numerator and denominator to estimate injury rate, accounting for the time spent in specific activities and included a procedure to estimate variance using the combined surveys.

Methods The 2010 National Health Interview Survey (NHIS) was used to quantify injuries, and the 2010 American Time Use Survey (ATUS) was used to quantify time of exposure to specific activities. The injury rate was estimated by dividing the average number of injuries (from NHIS) by average exposure hours (from ATUS), both measured for specific activities. The variance was calculated using the 'delta method', a general method for variance estimation with complex surveys.

Results Among the five types of injuries examined, 'sport and exercise' had the highest rate (12.64 injuries per 100 000 h), followed by 'working around house/yard' (6.14), driving/riding a motor vehicle (2.98), working (1.45) and sleeping/resting/eating/drinking (0.23). The results show a ranking of injury rate by activity quite different from estimates using population as the denominator.

Conclusions Our approach produces an estimate of injury risk which includes activity exposure time and may more reliably reflect the underlying injury risks, offering an alternative method for injury surveillance and research.

INTRODUCTION

Non-fatal injury posts a substantial burden on the nation's health and safety. The US National Center for Health Statistics (NCHS) estimated that in 2012 over 30 million non-fatal injuries required medical attention;¹ the lifetime medical and work-loss costs associated with non-fatal injuries totalled over \$457 billion in 2013.² There is no daily routine or activity that is genuinely free from injury risk, but if certain activities are known to have higher injury risk, appropriate task-based intervention strategies could be developed and tracked, which may prevent more injuries from occurring.

In order to calculate injury rates by activity, both injury cases, known to occur while performing specific activities, and exposure time of the same activities need to be collected. In reality, few national

surveys have the capacity to collect both numerator and denominator statistics. For example, the National Health Interview Survey (NHIS) asks respondents to report the occurrence of injuries and also inquires about activities performed at the time of injury (working, driving, etc.). However, the survey does not record the exposure time corresponding to these activities except for usual weekly work hours. As such, with data from the NHIS alone it is not possible to estimate injury rates in terms of exposure hours.

In the absence of information about exposure hours in the estimation of risk, researchers typically report the frequency of injuries by activity grouping and often report the 'injury rate per population', that is, the number of injuries that occur in a population at risk in a given time period, to describe injury risk at the population level.^{1 3-6} As a basic and important epidemiological measure, this expression of injury risk is widely used. In the case of the NHIS since no exposure time in each activity is gathered, the population (estimated directly from the NHIS)⁴ is used as the denominator, and the rate per population by activity (or by cause) basically reflects the relative distribution of injury cases by activities (or by cause).^{1 3-6}

However, the injury rate per population calculated this way does not take into account exposure hours in the calculation and may conceal the true picture of injury risk per unit time exposed.^{7 8} Moreover, because the population at risk is often treated as a constant,³⁻⁶ this expression of risk implicitly assumes that the exposure for the entire population is identical for all different types of activities, which may overstate the exposure time of activities where people typically spend less time (eg, sports and exercising) relative to the activities that people spend more time (eg, working). Thus, rate per population should not be used to compare injury risk between different activities or demographic groups where time exposed to specific activities is known to vary.

A further refinement of the expression of injury risk is warranted given the availability of adequate denominator statistics. To estimate injury rates by activity that take into account exposure time, we combine statistics from two national complex surveys for the numerator and denominator as inputs for the numerator and denominator of rate calculation. We adopt a method to estimate the variance of the injury rates that takes into account the complex survey designs. Using different national surveys for the numerator and denominator of rate



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calculation is an approach first employed to assess the association between smoking and lung cancer,⁹ and has been applied to other topics, particularly cancer mortality.^{10–15}

Some studies have examined the injury rate of certain activities in the USA such as transportation fatalities¹⁶ or fatal workplace injuries¹⁷ similarly using different data sources for the numerator and denominator. However, these studies are concerned about specific injuries or specific subpopulations; no previous research has attempted to examine a wide spectrum of activities in which people are engaged on a daily basis. We add to the literature by estimating injury rates of all possible activities (known as person-time incidence rate or incidence density rate) for which no national estimates have been produced. We also demonstrate the ability to approximate the variance of the rates that integrates the complex survey designs of both numerator and denominator data.

METHODS

Data

We used the 2010 US adult population to illustrate the procedures. The numerator data, or injury outcomes, came from the 2010 NHIS¹⁸; the denominator data, or exposure time data, came from the 2010 American Time Use Survey (ATUS).¹⁹ The NHIS is a cross-sectional household interview survey that has been monitoring the US population’s health since 1957, where the target universe of the NHIS is the civilian non-institutionalised population.¹⁸ The NHIS uses multistage sampling that involves stratification, clustering and oversampling of specific population subgroups. The survey is administered by the US Census Bureau under a contractual agreement with the NCHS. We used NHIS data for 2010, extracted from the Integrated Health Interview Series database,²⁰ and restricted analyses to those aged 18+. There were 27 157 adult observations in our analysis, and the response rate in 2010 was 79.5%.¹⁸

For the main portion of the interview, ‘Family Core’, all members of the household 18 years of age and over who are at home at the time of the interview are invited to participate and to respond for themselves.¹⁸ For adults not available for interview, information is provided by another adult family member in the household. The Family Core includes an injury and poisoning section, in which the respondents report each injury or poisoning episodes that was severe enough to seek medical treatment 3 months prior to the interview. Additional supporting information on the nature and circumstances of the injury is also gathered. We excluded the poisoning episodes, and only used injury episodes that occurred within a 6-week recall period (as opposed to 3 months) because studies^{4 21} showed that recall bias increases with the time elapsed between injury and interview, especially after 6 weeks.

The ATUS measures the amount of time people spend performing various activities; the survey started in 2003 and has been collected annually. The target universe is composed of the civilian, non-institutionalised population that are at least 15 years of age residing in occupied households in the USA.¹⁹ The ATUS is a stratified, three-stage sample where an eligible person is randomly selected from the household to conduct the interview and to participate in a 24-h time-use diary that documents the time spent in specific activities that are then coded using a standardised lexicon.²² The ATUS is conducted by the US Census Bureau for the US Bureau of Labor Statistics. We used ATUS data for 2010, extracted from the ATUS-X database,²³ and restricted analyses for persons 18+. There were

16 679 adult observations in our analysis and the response rate of the ATUS in 2010 was 56.9%.¹⁹

The NHIS inquires about activities that were being performed at the time of injury after the respondent describes the circumstances leading to the incident; there are 11 categorical options.²⁴ We estimated the rate of injury for the following five categories (as worded in the NHIS questionnaire):²⁴ (1) working at a paid job, (2) sports and exercise, (3) sleep, resting, eating, drinking, (4) working around the house/yard and (5) driving/riding in a motor vehicle. These activities were selected because the ATUS has recorded time use in a 24 h period in a much more detailed manner, which could be appropriately collapsed to allow matching of hours exposed corresponding to each of those five categories in the NHIS. The NHIS activities and corresponding collapsing of ATUS activities are described in table 1.

Calculation of injury rate per hour exposed and variance using statistics from different surveys for the numerator and denominator

We let Y be the number of injury episodes of US adults in 2010 and related to a specific activity, and let X be the same population’s total hours of exposure to the specific activity in 2010 that is also related to the same activity as the injury episodes. The rate per hour exposed is simply the ratio of Y to X, which we estimated using the ratio of the corresponding sample means \bar{Y} and \bar{X} ,²⁵ assuming both surveys generalise to the same population:

$$R = \frac{Y}{X}$$

$$\hat{R} = \frac{\bar{Y}}{\bar{X}} \tag{1}$$

The sample means \bar{Y} and \bar{X} were calculated individually, incorporating the survey-appropriate sampling weights. Both \bar{Y} and \bar{X} were annualised, because in the calculation of a rate the numerator and denominator need to have the same calendar period time, which in our study was the year of 2010. Since we have restricted the recall period of injury episodes to 6 weeks

Table 1 Correspondence between 2010 NHIS and 2010 ATUS activities

NHIS: activities performed at the time of injury	ATUS activity categories and the associated activity codes
Working at a paid job	Everything in the ‘work and work-related’ category (05xxxx)
Sports or exercise	Everything in ‘participating in sport, exercise, or recreation’ category (1301xx), plus ‘waiting related to playing sports or exercising’ (130301) and ‘security related to playing sports or exercising’ (130401)
Sleeping, resting, eating or drinking	‘Sleeping’ (0101xx) and ‘eating and drinking’ (11xxxx)
Working around the house or yard	Everything in ‘Household Activities’ category (02xxxx) except for ‘walking, exercising, playing with animals’ (020603) and cooking (0202xx)
Driving or riding in a motor vehicle	Everything in the ‘travelling’ category (181101-189999) and ‘transportation mode’=driving or riding in a motor vehicle (bus, train, car, etc.)

Note: ‘xx’ or ‘xxxx’ indicates every item in the broader category. ATUS, American Time Use Survey; NHIS, National Health Interview Survey.

(42 days), the annualised estimate \bar{Y} was calculated by multiplying the weighted 6-week averages by 365/42,⁴ with the assumption that the injury pattern over a 6-week period represents that of a year.²⁶ The time-diary data of ATUS were collected for a single day and weekend days were over-represented (50% of the sample data). The weighting variables were constructed to reduce the impact of over-representation of weekend days so that the weighted estimates represent a 'typical day' in a calendar quarter.¹⁹ The annualised estimates were obtained by multiplying the weighted daily averages by 365,¹⁹ assuming that the 'typical day' in the calendar quarter (after weighting) represents the time-use pattern throughout the year.

The variance of \hat{R} , $\text{VAR}(\hat{R})$, was approximated using the 'delta method',²⁷⁻²⁸ which is essentially a first-order Taylor series expansion. The delta method has been used extensively in statistics²⁵ and can be applied to different sampling designs.²⁵⁻²⁹ (StataCorp, LP: Stata Survey Data Reference Manual, Release 13. College Station, Texas: Stata Press Publication 2013). This method is the default approach for variance estimation with complex surveys of SAS, SUDAAN³⁰ and Stata (StataCorp, LP: Stata Survey Data Reference Manual, Release 13. College Station, Texas: Stata Press Publication 2013.) and has been employed in a wide array of studies including those using complex surveys as their data.³¹⁻³² Chapter 9 of *Sampling: Design and Analysis* (Lohr)²⁵ describes the method in detail. The delta method²⁸ shows that the variance can be approximated by a combination of $\text{VAR}(\bar{Y})$, $\text{VAR}(\bar{X})$, \bar{Y} and \bar{X} (online supplementary material provides the details of the derivation):

$$\text{VAR}\left(\frac{\bar{Y}}{\bar{X}}\right) \cong \frac{\text{VAR}(\bar{Y})}{\bar{X}^2} + \frac{\bar{Y}^2 \cdot \text{VAR}(\bar{X})}{\bar{X}^4} \quad (2)$$

If the data source for the numerator or denominator is a complex survey, the calculation of $\text{VAR}(\bar{Y})$, $\text{VAR}(\bar{X})$, \bar{Y} and \bar{X} needs to include the survey designs so that the design information is appropriately reflected in $\text{VAR}(\bar{Y}/\bar{X})$. Operationally, we did this by using the Stata command 'svy: mean'(Stata Corporation LP, 2013) to calculate \bar{X} , \bar{Y} , $\text{VAR}(\bar{X})$ and $\text{VAR}(\bar{Y})$ individually, and substituted them into equation (2) to obtain $\text{VAR}(\bar{Y}/\bar{X})$. The $\text{SE}(\bar{Y}/\bar{X})$ was obtained by taking the square root of $\text{VAR}(\bar{Y}/\bar{X})$. Stata V.13 was used for all analyses.

Comparing the results with rate-per-population estimates and those using the NHIS data alone

To illustrate the difference between different expressions of injury risk, we estimated injury rate per population and contrasted the results with rate per hour exposed. Similar to the method used to calculate rate per hour exposed, the numerator was the number of injury episodes. Converse to the rate per

hour approach was that the adult population (estimated directly from the NHIS)¹⁻⁴ was used as the denominator. The NCHS has constantly provided annualised injury risk estimates,¹⁻⁴ we followed this convention.

RESULTS

There were 12 679 adult observations in the 2010 ATUS, and 27 157 in the 2010 NHIS. The demographic profile (weighted) of the two samples was similar. The mean age was 46.2% and 46.3%, and the proportion of females versus males was 51.7% and 51.6% for the NHIS and ATUS, respectively. The left panel of table 2 summarises the average numbers of injuries an adult would sustain over a year (ie, the \bar{Y} in equation 1) as well as the SEs (ie, the square root of $\text{VAR}(\bar{Y})$ in equation 2). The right panel summarises the average activity exposure time over a year (ie, the \bar{X} in equation 1). The calculation of \bar{Y} , $\text{SE}(\bar{Y})$, \bar{X} and $\text{SE}(\bar{X})$ took into account appropriate survey designs.

Table 3 reports the estimated injury rates per hour of activity exposed. To compare the injury risk associated with different activities, the rates were normalised to 'number of injury episodes per 100 000 h' for each type of activity.

US adults sustained 1.45 injuries per 100 000 work hours (table 3). The comparable figure was 12.64, 0.23, 6.14 and 2.98 injuries per 100 000 h for the other four categories, respectively.

Table 4 describes injury rates per 1000 persons (population) for the same five activity types. The injury rate-per-hour approach depicts a ranking of injury risk quite different from the rate-per-population approach. For example, the injury rate per hour exposed in a sport activity was 4.24 times as high as the injury rate per hour exposed to driving (table 3). By contrast, the rate per population in a sport activity was only 1.08 times as high as rate per population exposed to driving (table 4).

DISCUSSION

We combined statistics from two different complex national surveys for the numerator and denominator to estimate injury rates per hour exposed by activity, and approximated the variance using the delta method, a commonly used method for variance estimation with complex surveys.²⁵⁻³¹⁻³² Researchers in other fields have combined statistics from two surveys to generate ratio estimates,⁹⁻¹⁵ although this approach has not been accomplished to estimate injury rates by activity groupings. By combining these two complex surveys and incorporating the time spent in specific activities, we identified a different rank order of injury risk compared with using a per person risk metric.

We compared our estimates for work-related injuries with those using the 2010 NHIS data alone; the results were close. The NHIS asks 'usual work hours per week' (but not time use

Table 2 NHIS average number of injuries and ATUS average exposure hours by activity

	NHIS injury		ATUS exposure time	
	Average number of injuries (individual level) over one year (ie, \bar{Y})	$\text{SE}(\bar{Y})$	Average exposure hours (individual level) over 1 year (ie, \bar{X})	$\text{SE}(\bar{X})$
Work-related	0.0277	0.0043	1911.6	23.9
Sports or exercise	0.0129	0.0022	101.7	3.8
Sleep, rest, eating, drinking	0.0084	0.0020	3565.9	10.4
Working around the house or yard	0.0282	0.0034	459.1	8.5
Driving/riding a motor vehicle	0.0120	0.0019	400.8	5.2

ATUS, American Time Use Survey; NHIS, National Health Interview Survey.

Table 3 Injury rate per 100 000 h (number of injuries per 100 000 exposure hours) of US adults by activities performed at the time of injury, using 2010 NHIS (numerator) and ATUS (denominator)

All	Work	Sport and exercise	Sleeping, resting, eating, drinking	Working around house/yard	Driving/riding a motor vehicle
Rate	1.45	12.64	0.23	6.14	2.98
SE	0.22	2.23	0.06	0.75	0.49
95% CI	1.01 to 1.89	8.28 to 17.01	0.13 to 0.34	4.66 to 7.61	2.03 to 3.94

ATUS, American Time Use Survey; NHIS, National Health Interview Survey.

for the other five activities) which can serve as the denominator. The estimate was 1.40 injuries per 100 000 work hours (95% CI (1.02 to 1.78)), slightly lower but comparable with the current study (1.45 injuries per 100 000 work hours, table 3) which used the ATUS for the denominator. The difference is expected because people tend to overstate ‘usual hours worked’ compared with time-diary measures.³³ As such, the average exposure hours of the NHIS may be greater than the ATUS, rendering a rate estimate (1.40 injuries per 100 000 h) slightly lower than the current study (1.45 injuries per 100 000 h).

The major advantage of our approach (ie, injury rate per hour) is that we could control for the amount of time a person was exposed to a specific activity by explicitly using exposure hours as the denominator, which may more reliably indicate the underlying injury risk than the rate-per-population approach. Rate per hour is also more suitable for comparing injury risks across different activities or demographic groups than rate per population.^{7 8 34} Furthermore, by allowing the numerator and denominator to use different data sources, it becomes possible to measure the injury risk when data availability is constrained, in particular when no data source has documented both the injury and exposure time for a subject of interest. However, the rate-per-population approach is useful to understand the magnitude of injury burden across different populations or demographic groups; estimates based on this approach are also more readily accessible.^{1 3–6} Both approaches have their unique strengths and limitations, and should be interpreted based on the research context.

The major limitation of our approach is that for a given domain of interest (eg, leisure), the information collected by the different surveys may not be perfectly comparable. For example, for injuries that occur while people are ‘sleeping, resting, eating, drinking’, the ATUS does not record time specifically spent resting, but only sleeping, eating or drinking. Thus, the exposure time in our study may be underestimated and the rate overestimated. While the ATUS and NHIS do collect information on industry and occupation, there are not sufficient numbers of observations for cases and exposure hours to generate reliable estimates for individual industries or occupations on an annual basis. Moreover, both the ATUS and NHIS do not capture specific activities within any occupations, such as mining or logging. Working as a miner is conceivably more dangerous than working at a computer, yet for the work-related injuries

and activities as collected by the NHIS and ATUS all these different types of work (both of high and low risk) are combined into a single ‘work’ category. Finally, an activity that has lower-ranked injury rates may still be a major public health problem whose significance should not be downplayed. For example, the injury rate per hour of work is much lower than playing sports. However, people on average spend much more time working than playing sports; because of a greater amount of exposure time, work-related injuries still outnumber sports injuries by a factor of two (table 4). Beyond injury rates, we note that activities vary in the extent to which they provide health or other life benefits. However, as our focus in this manuscript was methodological, we did not assess these potential trade-offs.

An additional limitation is that both the ATUS and NHIS are self-reported data; incorrect recall may vary between different types of injuries which may bias the estimate for injury risk of one category relative to others. We assumed that the two surveys, both conducted in 2010, generalised to the same population (people age 18+). Indeed both surveys have been poststratified to make the population estimates by major demographic variables match the known population distributions as much as possible. However, NHIS and ATUS used different poststratification procedures, and the estimated population totals of one survey may be different from the other. Some categories have a small number of injury cases and the estimates and the CIs may not be reliable. This issue could be potentially addressed by pooling multiple years of ATUS and NHIS data, but it is unclear how to adjust for the correlation across years when combining data from two complex surveys for ratio estimates.

CONCLUSION

Non-fatal injury posts a substantial burden on the nation’s health and safety, and it is important to quantify and compare the injury risk of different activities that people are engaged in on a daily basis for accurate estimation of injury risk. We adopted a procedure that allows the use of different national complex surveys for the numerator and denominator to derive estimates of the rate of injury by activity as well as variance estimates. Our results depicted a ranking of injury rates using hours spent engaged in an activity that are different from estimates using population as the denominator.^{3 6} This procedure produced estimates that may more accurately reflect the underlying

Table 4 Annualised injury rate per 1000 population (number of injury episodes per 1000 persons) of US adults by activities performed at the time of injury, using 2010 NHIS for the numerator and denominator

All	Work	Sport and exercise	Sleeping, resting, eating, drinking	Working around house/yard	Driving, riding a motor vehicle
Rate	27.68	12.86	8.36	28.17	11.96
SE	4.28	2.21	1.97	3.42	1.95
95% CI	19.29 to 36.06	8.52 to 17.19	4.50 to 12.22	21.46 to 34.87	8.14 to 15.78

NHIS, National Health Interview Survey.

injury risk and may be used to compare across different types of injuries or demographic groups. This procedure also overcomes data availability constraints frequently encountered by injury researchers, making it possible to estimate injury risk and CIs even when no single survey has collected information on both injury cases and activity exposure time.

Key messages

What is already known on the subject

- ▶ Few surveys collect both injury cases and exposure time, making it difficult to generate exposure time-based estimates for injury risk of common day-to-day activities.
- ▶ In the absence of exposure time data, researchers often report the number of injuries that occur in a population at risk in a given time period, or 'injury rate per population.'
- ▶ The rate-per-population approach reflects the magnitude of injury burden of a population, but may conceal the true picture of injury risk per unit time exposed.

What is this study adds

- ▶ To estimate injury rates by activity that account for exposure time, statistics from two national complex surveys were separately used as inputs for the numerator and denominator in the rate calculation.
- ▶ To calculate the variance of the rates, we use the 'delta method'.
- ▶ Our results demonstrate a different ranking of injury rate by activity as compared to ranked estimates using population as the denominator.
- ▶ Our approach enables one to estimate injury risk and variance by combining injury cases and activity exposure time from separate surveys.

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Contributors HRM-W developed the concept of the study; TL implemented the study design with contributions from HRM-W, JLW and SKV. TL performed the analysis and drafted the first version of the paper. JLW, SKV, HRM-W and TL contributed to the interpretation of the data. All five authors have performed a critical review of the manuscript and have approved this final version for publication.

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