The Public Health Burden of TBI: A 1% or 10% Problem?

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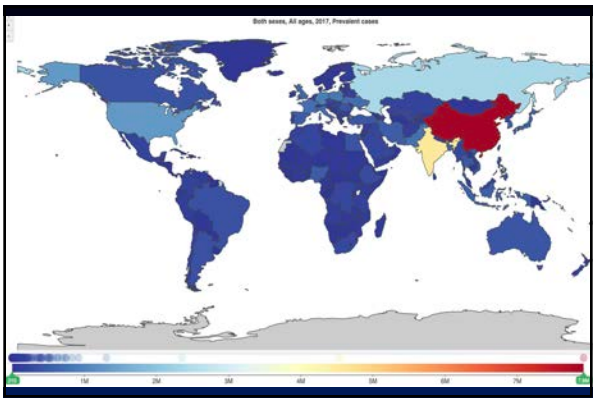
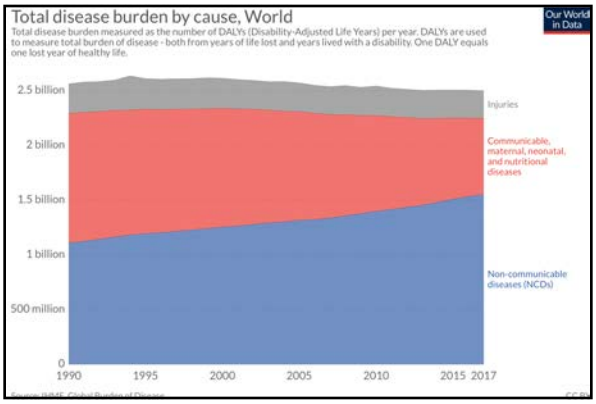
No Financial Conflicts of Interest

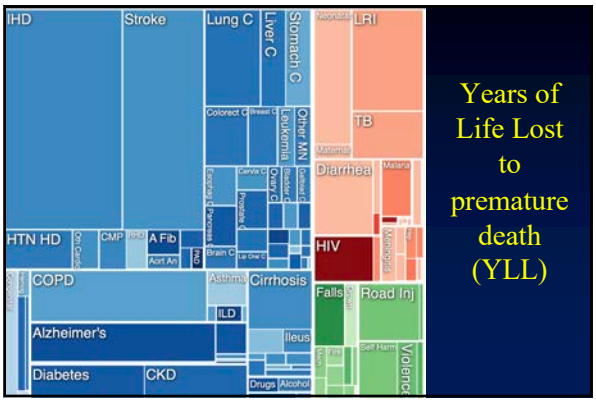
- I receive funding from the National Institute on Disability Independent Living and Rehabilitation Research (NIDILRR), the National Institutes of Health (NIH) and the Patient Centered Outcomes Research Institute (PCORI).
- I created the Ohio State University TBI Identification Method (OSU TBI-ID) which is available for free.
- I am a member of the Board of Directors of the Brain Injury Association of America.

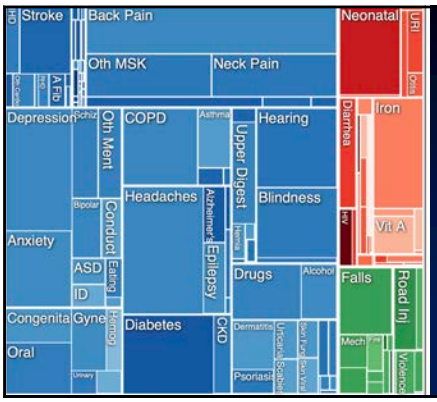
First, an apology

- public health "burden"
- equating "living with disability" to premature death

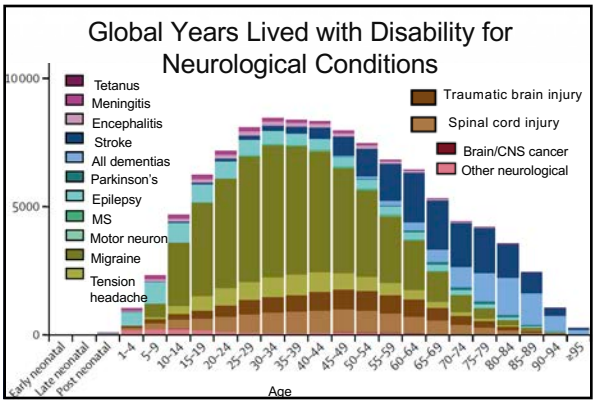


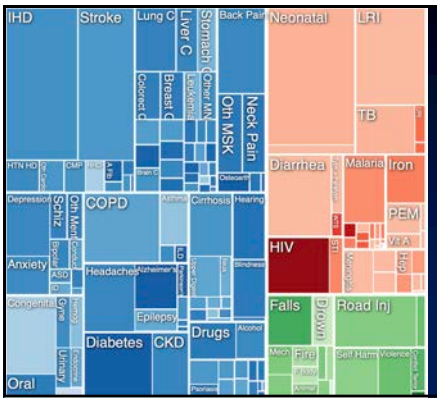

Total disease burden by cause, World
Total disease burden measured as the number of DALYs (Disability-Adjusted Life Years) per year. DALYs are used to measure total burden of disease - both from years of life lost and years lived with a disability. One DALY equals one lost year of healthy life.
Our World in Data
2.5 billion
2 billion
1.5 billion
1 billion
500 million
0
1990
1995
2000
2005
2010
2015
2017
Injuries
Communicable, maternal, neonatal, and nutritional diseases
Non-communicable diseases (NCDs)


IHD
Stroke
Lung C
Liver C
Stomach C
LRI
TB
Diarrhea
HIV
HTN HD
A Fib
COPD
Cirrhosis
Alzheimer's
Diabetes
CKD
Falls
Road Inj
Violence
Years of Life Lost to premature death (YLL)



Years Lived with Disability (YLD)





Disability Adjusted Life Years (DALY = YLL+ YLD)

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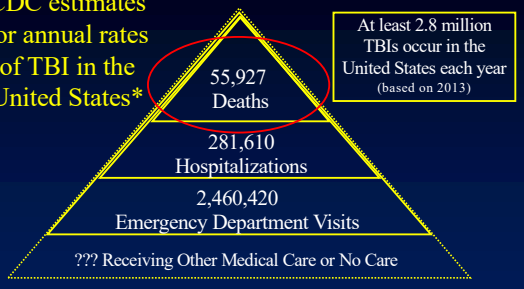
Global Burden of Health

- YLL = Years of Life Lost to premature death
- YLD = Years Lived with Disability
- DALY = Disability Adjusted Life Years is the sum of YLL and YLD
- Incidence = number of episodes of the disease/disorder
- Mortality = number of lives lost
- Disability = how many people live with disability due to the disease/disorder
- Prevalence = persons living with disability due to the disease/disorder

Years of Life Lost Due to TBI

CDC estimates for annual rates of TBI in the United States*



At least 2.8 million TBIs occur in the United States each year (based on 2013)

* Taylor, CA, JM Bell, MJ Breiding and L Xu: Traumatic brain injury-related emergency department visits, hospitalizations, and deaths - United States, 2007 and 2013. MMWR Surveill Summ 66(9): 1-16, 2017

JOURNAL OF NEUROTRAUMA 32:1893–1901 (December 1, 2015)

DOI: 10.1089/neu.2014.3353

Life Expectancy after Inpatient Rehabilitation for Traumatic Brain Injury in the United States

Cynthia Harrison-Felix,[1] Christopher Pretz,[1] Flora M. Hammond,[2] Jeffrey P. Cuthbert,[1] Jeneita Bell,[3] John Corrigan,[4] A. Cate Miller,[5] and Juliet Haarbauer-Krupa[3]

Methods

- 7,366 TBI Model Systems participants admitted for rehabilitation after 10/01/2001 and discharged by 12/31/2010 with vital status tracked until 12/31/2011. (20,314 person-years of data)
- Weighted for national population characteristics to represent 156,447 individuals admitted to U.S. inpatient rehabilitation facilities with a primary diagnosis of TBI ages 16+ during same time period.
- Used U.S. population mortality rates from 2005 and 2010 to calculate standardized mortality ratios and life expectancy.

Overall Results

	Observed Deaths	Expected Deaths	Standardized Mortality Ratio (SMR)	95% Confidence Interval
All participants	1,325.4	594.7	**2.23**	2.11, 2.35
If alive 1 year post-injury	879.2	570.7	**1.54**	1.44, 1.64

- Individuals with TBI were 2.23 times more likely to die compared to individuals in US general population of similar age, gender and race.
- Excess mortality decreased for those who survived at least until their 1 year post-injury anniversary.

Age

	Observed Deaths	Expected Deaths	SMR	95% Confidence Interval
Age at injury (years)				
15-19	7.6	0.7	**11.58**	3.37 - 19.79
20-24	17.1	2.5	**6.86**	3.60 - 10.11
25-34	26.9	3.3	**8.24**	5.12 - 11.35
35-44	46.6	4.9	**9.56**	6.82 - 12.31
45-54	104.2	12.2	**8.55**	6.91 - 10.19
55-64	107.5	21.3	**5.04**	4.09 - 5.99
65-74	245.1	55.6	**4.41**	3.86 - 4.96
75-84	530.0	200.8	**2.64**	2.41 - 2.86
85+	240.3	293.5	**0.82**	0.72 - 0.92

Generally, as age at injury increased, excess mortality decreased, but still remained elevated to age 84.

Independent risk factors for death

- Older age at injury
- Being male
- Divorced, widowed or separated
- Unemployed
- Less education
- Fall related TBI
- Later year of injury
- Not having a spinal cord injury
- Not discharged home
- Lower functional independence
- Greater disability

Independent risk factors for death

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- Not having a spinal cord injury
- Not discharged home
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Cause of Death	Actual Deaths	Expected Deaths	SMR	SMR 95% limits
Seizures	13.3	.3	**50.00**	23.15, 76.84
Accidental Poisoning	20.7	1.9	**10.68**	6.08, 15.28
Sepsis	76.3	8.1	**9.37**	7.26, 11.47
Aspiration Pneumonia	36.6	5.7	**6.40**	4.33, 8.48
Fall	30.7	5.7	**5.35**	3.46, 7.24
Homicide	7.1	1.4	**4.92**	1.30, 8.54
Pneumonia	80.0	19.3	**4.15**	3.24, 5.06
All External Causes	92.8	23.7	**3.91**	3.12, 4.71
Vehicular	17.6	5.1	**3.44**	1.83, 5.05
Suicide	10.1	3.83	**2.64**	1.01, 4.27
All Respiratory	176.6	67.5	**2.62**	2.23, 3.00
Mental/Behavioral	47.4	21.8	**2.17**	1.55, 2.79
Nervous System	63.8	35.9	**1.78**	1.34, 2.21
Digestive	27.4	18.2	**1.51**	0.94, 2.07
Circulatory	340.8	239.8	**1.42**	1.27, 1.57

McMillan TM, Weir CJ, Wainman-Lefley J.
J Neurol Neurosurg Psychiatry 2014;85: 1214–1220.

Mortality and morbidity 15 years after hospital admission with mild head injury: a prospective case-controlled population study

McMillan TM, Weir CJ, Wainman-Lefley J.
J Neurol Neurosurg Psychiatry 2014;85: 1214–1220.

Table 1 Deaths in 15 years per 1000 per year by age category (95% CIs)

Group	Aged <55 years at study entry	Aged ≥55 years at study entry
Mild head injury	12.89 (11.66 to 14.20)	51.37 (49.22 to 53.37)
Other injury control	7.51 (6.53 to 8.58)	47.72 (45.44 to 49.89)
Community control	3.07 (2.43 to 3.80)	37.16 (34.70 to 39.58)

McMillan TM, Weir CJ, Wainman-Lefley J.
J Neurol Neurosurg Psychiatry 2014;85: 1214–1220.

Table 2 Association between patient characteristics and death at 15 years for the MHI group only (multiple logistic regression: forward stepwise variable selection)

MHI group	OR	OR 95% CI	p Value
Age (per additional 5 years)	1.43	(1.37 to 1.50)	<0.0001
Habitual alcohol excess	1.85	(1.33 to 2.57)	0.00023
Number of previous admissions with head injury	1.24	(1.05 to 1.48)	0.013
Previous physical limitation	1.80	(1.29 to 2.53)	0.00063
SIMD 2006 (per quintile)	1.23	(1.09 to 1.40)	0.0012

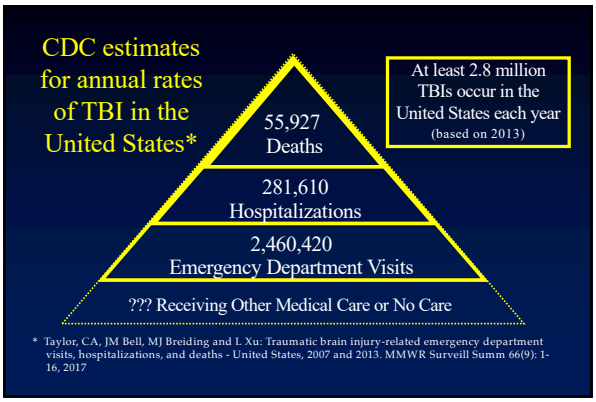
MHI, mild head injury; SIMD, Scottish Index of Multiple Deprivation.

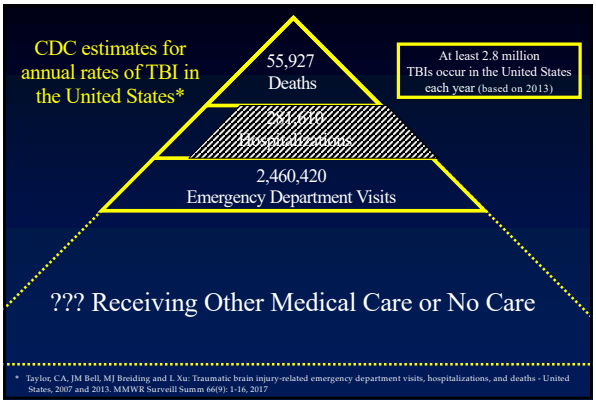
Summary: Years of Life Lost Due to TBI

- Years of life lost to TBI is underestimated due to not accounting for chronic effects on mortality.
- Excess mortality:
  - greatest in younger persons
  - evident in mild as well as moderate/severe TBI

What about years of life lived with disability?

Prevalence of Disability Due to TBI





Prevalence of Disability Due to TBI

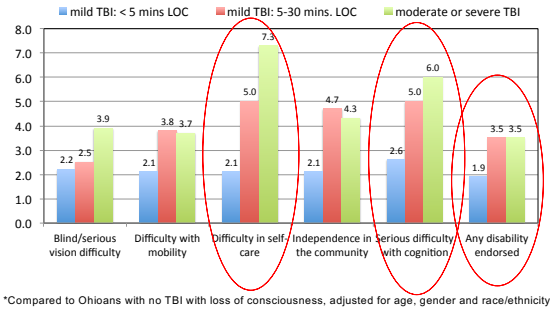
- Projected from 1 year outcomes following hospitalization
- Datasets did not include children
- Made assumptions about persistence of disability and mortality

✓In 1996, based on Colorado data: 2.0%
✓In 2005, based on South Carolina data: 1.1%

Population Surveys of Disability Due to TBI

- Jourdan et al. from the French National Disability and Health Survey: 0.7%
- Ohio BRFSS survey of non-institutionalized adults with disability and history of moderate/severe TBI: 1.2%

Adjusted Odds* of Disability by Severity of Worst Lifetime TBI



*Compared to Ohioans with no TBI with loss of consciousness, adjusted for age, gender and race/ethnicity

Summary: Prevalence of Disability Due to TBI

- Estimates have ranged from 0.7%–2.0%
- US studies likely underestimates due to:
  - Starting with disability 1 year after hospitalization
  - Having to make assumptions about permanence and mortality
  - Not including TBIs occurring in childhood

What if the effect of the TBI is not apparent immediately but in time results in disability or other consequences?

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Ohio State University

"Exposure" to TBI

"Exposure" to TBI

If TBI was a chemical we would ask:

- What is the relationship between the dose of the exposure and the effect on the person?
- Can there be cumulative effects of repeated exposures?
- How does development interact with both exposure and the manifestation of the effect?

Conceptualizing "Exposure" to TBI

- How does the magnitude of altered consciousness affect later consequences?—i.e., severity as dose
- How many TBIs has a person had and what was their timing?—i.e., number and spacing as the source of cumulative effects
- How old was a person when TBI occurred?—i.e., interaction with the stage of development

Use of standardized instruments for elicitation of the characteristics of lifetime TBI in the general population has been limited, at least to date.

Lifetime History of TBI in General Population Surveys using Standardized Instruments

Colorado: CDC funded survey of 2,701 non-institutionalized adults. Conducted 2008-2010 using CATI of the OSU TBI Identification Method research version.

Ohio: State optional module included in 2014 BRFSS administered to 6,998 non-institutionalized adults. Used adapted OSU TBI Identification Method.

North Carolina: State optional module included in 2017 BRFSS administered to 3,769 non-institutionalized adults. Used adapted OSU TBI Identification Method.

Prevalence of TBI in the Adult, General Population

	Colorado	Ohio	North Carolina
% with Any TBI	42.5%	n/a	n/a
% with Loss of Consciousness	24.4%	21.7%	24.4%
% with Moderate or Severe TBI	6.0%	2.6%	4.4%
% with Loss of Consciousness before age 15	6.7%	9.1%	12.2%*
% either LOC < 15 or mod/sev TBI	11.5%	10.8%	?

* In North Carolina, before the age of 18

Summary: Prevalence of TBI Exposures

- "Exposure" is a paradigm shift in previous approaches to prevalence
- Accounts for effects of TBI that are not immediate and continuous
- May be more important when considering the public health burden of TBI
- Do not know enough about prevalence of exposure

What do we know about consequences of lifetime exposure?

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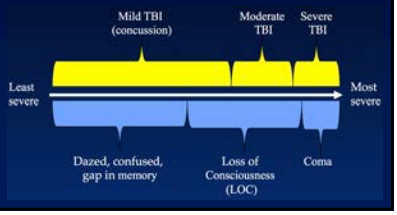
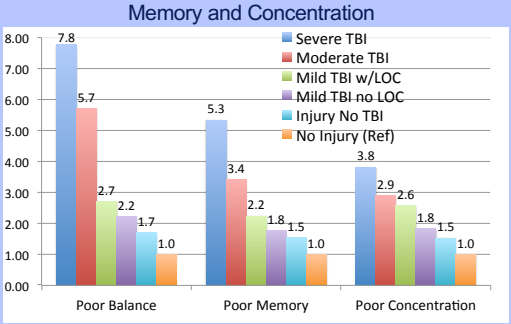
Consequences of Exposure to TBI

Severity as Dose

Are consequences more likely with more severe TBIs?

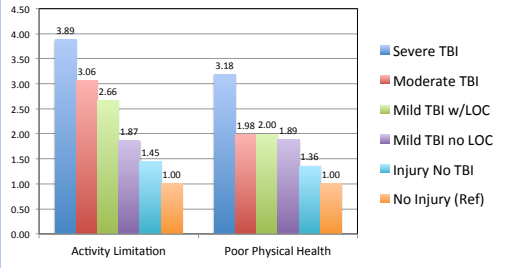


Colorado: Relative Prevalence of Poor Balance, Memory and Concentration



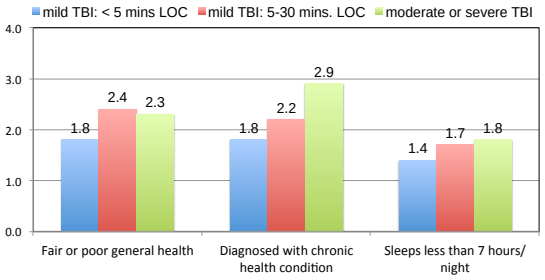
Compared to those with no injuries after controlling for age, gender, race and treatment received (i.e., hospital, ED, office, none)

Colorado: Relative Prevalence of Activity Limitations and Poor Physical Health



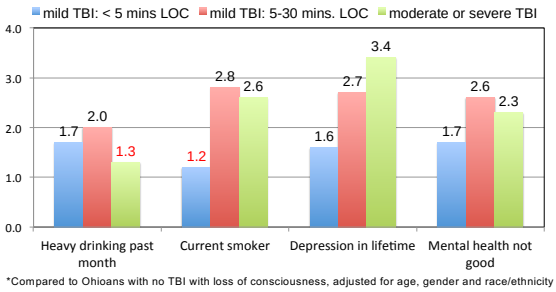
Compared to those with no injuries after controlling for age, gender, race and treatment received (i.e., hospital, ED, office, none)

Adjusted Odds* of Unhealthy Conditions by Severity of Worst Lifetime TBI



*Compared to Ohioans with no TBI with loss of consciousness, adjusted for age, gender and race/ethnicity

Adjusted Odds* of Behavioral Health Issues by Severity of Worst Lifetime TBI



*Compared to Ohioans with no TBI with loss of consciousness, adjusted for age, gender and race/ethnicity

Developmental Contributions

Do childhood TBIs, even if mild, have adult consequences?

Findings from 3 international studies

Natural History of TBI to Age 25
(McKinlay et al., 2008, 2009, 2013)

- 1,265 children born in 1977 in Christchurch, New Zealand and followed to age 25
- Annual assessments from 4 months to age 16, then at 18, 21 and 25
- Verified through medical records all TBI's diagnosed by a professional (MD office, ED, hospitalized)
- 79.3% successfully followed through age 25

Early Injury as Predictor of Later Problems

Compared to no TBI and outpatient only, by early adolescence (10-13 y.o.) those hospitalized with a mild TBI before age 6 were:

- More hyperactive and inattentive as rated by parent and teacher
- More likely dx'd with ADHD, conduct disorder or oppositional defiant behavior
- More likely to have substance abuse problems
- More likely to demonstrate mood disorders

Early Injury as Predictor of Later Problems (continued)

By late adolescence to early adulthood (16-25 years old):

- Those hospitalized with 1st TBI before age 6, 3 times more likely to have a diagnosis of either alcohol or drug dependence by age 25
- Those hospitalized with 1st TBI 16-21, 3 times more likely to be diagnosed with drug dependence
- TBI highly associated with likelihood of arrest

Avon Longitudinal Study

(Kennedy, Heron & Munafo, 2017)

- 11,400 children born 1991-1992 in southwest region of the UK
- 800 mild TBI, 2,300 orthopedic controls, 8,300 uninjured through age 16
- Likelihood of substance abuse, psychiatric co-morbidities and offending @ age 17
- Accounted for pre-birth, adverse events and parental characteristics

Avon Longitudinal Study (continued)

- Alcohol misuse more likely for mTBI than either uninjured (OR=1.56, 1.21-2.01) or orthopedic injured (OR=1.47, 1.11-1.94)
- Cannabis misuse more likely for mTBI than uninjured (OR=1.39, 1.07-1.80) but not orthopedic injured
- Tobacco dependence more likely for mTBI than uninjured (OR=1.46, 1.06-2.01) but not orthopedic injured
- For criminal behavior, mTBI and orthopedic injured different from uninjured but not from each other
- For conduct problems mTBI different from no injury

Swedish Population Registry

(Sariaslan et al., 2016)

- 1.1 million Swedish citizens born between 1973 and 1985 and followed to 2013
- 9.1% had a medically treated TBI by age 25
- Compared outcomes to general population, siblings without TBI and persons with orthopedic injuries
- Looked at likelihood of the following outcomes:
  - psychiatric treatment
  - psychiatric hospitalization
  - premature mortality
  - disability from work
  - receiving welfare benefits
  - low educational attainment

Adjusted Odds of Negative Consequences Compared to Siblings Without TBI

	Any TBI	Mild TBI	Mod/Sev TBI	Recurrent TBI
Disability pension	1.49	1.36	2.06	2.22
Psychiatric visit	1.31	1.31	1.34	1.24
Psychiatric hospitalization	1.57	1.51	1.75	1.53
Premature mortality	1.40	1.26	1.92	1.59
Low education	1.28	1.25	1.37	1.28
Welfare recipiency	1.19	1.18	1.21	1.13

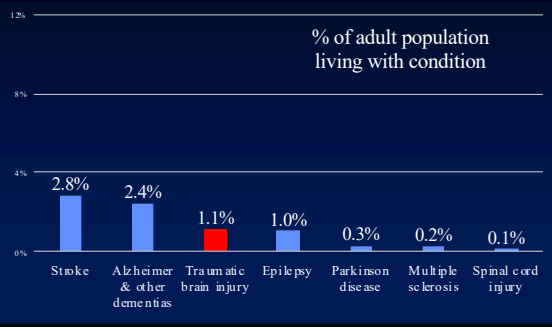
Other Characteristics of Exposure?

- Other developmental periods—e.g., middle age or older adult TBIs?
- Repetitive TBIs—i.e., experiencing another before the previous has healed?
- Cumulative effects of TBI + another source of brain compromise—e.g., anoxia, stroke?

Summary

- Significant associations between lifetime history of TBI and health and social consequences supports an "exposure" approach to examining the public health burden of TBI.
- There is much to learn about dose, cumulative and developmental effects.
- "Disability" due to TBI underestimates its consequences.

Prevalence of Neurological Disease in the U.S.



Commit to a brain healthy lifestyle!

- Avoid any more TBIs
- Eat well
- Exercise regularly
- Get at least 7 hours sleep
- Don't drink alcohol or use illicit drugs
- Stop smoking
- Be engaged with people & projects
- Seek to minimize the stress in your life
- Seek to increase restfulness with relaxation training, meditation or other practices

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THANK YOU

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