### Modeling individual and neighborhood level SES indicators on functional outcomes using the TBIMS database

Librada Callender, PhD, Raj Kumar, PhD

### Background

- This work fulfills a specific need to understand the influence of environmental and SES factors in addition to individual level factors on long-term recovery from TBI
- Prior research limited to individual level factors
- Project uses neighborhood-level characteristics from US. Census data to broadly contextualize variation in long-term functional outcomes among people post TBI

### Objective

- Parallel, cross-sectional analysis using the TBIMS NDB to compare models using individual and neighborhood level SES on TBI functional outcomes, with the goal of identifying the most parsimonious model to analyze SES impact
- Compare modeling diagnostics (R<sup>2</sup>, AIC, BIC) using the NSDI continuous variable and Neighborhood: Individual NSDI residual variable

### Sample

- Enrolled in TBIMS NDB aged 16 y/o or older at the time of injury with msTBI
- Outcomes collected at 2-, 5-, or 10- years post follow up
- Data from participants' most recent follow-up for which there is valid census tract information and completed individual level data

### Exposures

- (1) Individual-level SES variables
  - Household income
  - Years of education
  - Unemployment status at follow up

### Exposures

- (2) TBIMS-NSDI Composite Variable
  - American Community Survey (ACS) data from the Integrated Public Use Microdata Series (IPUMS) website linked to TBIMS census tracts derived from participant addresses
  - PCA to develop composite score using eight variables from ACS

Variable Name	Definition	Formula
TABLE 1 Description	n of variables comprising the	ТЫМБ-ІЛБІЛ

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Percent unemployed	The percentage of civilian unemployed (people 16 and over)	= (# civilian unemployed/# in labor force)
Percent single head of household	The percentage of single parent headed households with children <18	= ((# male household + # female household)/# in family households).
Percent with no high school diploma or GED	The percentage of people ≥25 years old without a high school diploma or GED	= (No schooling completed + nursery school + kindergarten + 1st through 11th grade + 12th grade, no diploma)/total in CensusTract
Percent with bachelor's or higher	The percentage of people ≥25 years old with a bachelor's degree or higher	= (Bachelor's degree + master's degree + professional school degree + doctorate degree)/total in CensusTract
Percent below poverty	The percentage of households with incomes in the past 12 months below poverty level	<ul> <li>Income in the past 12 months below poverty level/total for income versus poverty level)</li> </ul>
Percent SNAP	The percentage of households that received Food Stamps/SNAP in the past 12 months	<ul> <li>Household received Food Stamps-SNAP in the past 12 months/total for receipt of SNAP)</li> </ul>
Median household income	Median household income in the past 12 months (in inflation-adjusted dollars)	This variable was contained in the data set with no need for calculations
Median family income	Median family income in the past 12 months (in inflation-adjusted dollars)	This variable was contained in the data set with no need for calculations

### Exposures

- (3) Neighborhood: Individual NSDI residual group
  - Ordinary Least Squares (OLS) linear regression model with NSDI as the outcome as a function of the individual SES predictors: household income, education, and unemployment status
  - Calculated residuals (difference between the observed and predicted values of the NSDI at 2-, 5-, and 1-year follow up time points
  - Categorized into five qualitative subgroups

Neighborhood:Individual NSDI Residual Group Categories	Studentized Residual Values <sup>a</sup> (Min, Max)	Qualitative Description
Very low	(-2.86, -1)	Much less neighborhood disadvantage than predicted based on individual SES
Moderately low	(-1, -0.35)	Somewhat less neighborhood disadvantage than predicted based on individual SES
Near Zero	(-0.35, 0.35)	Close neighborhood disadvantage to predicted based on individual SES
Moderately high	(0.35, 1)	Somewhat higher neighborhood disadvantage than predicted based on individual SES
Very high	(1, 4.64)	Much higher neighborhood disadvantage than predicted based on individual SES

#### TABLE 2 Description of the sample by Neighborhood: Individual NSDI residual group

"By using a studentized residual, the residual value is interpreted in standard deviation units. For example, a person in the "very high" residual group would have an observed TBIMS-NSDI value over one standard deviation higher than their predicted value.

### Outcomes

**Continuous outcomes** 

- Participation Assessment with Recombined Tools Objective (PART-O) Rasch
- Disability Rating Scale
- Functional Independence Measure
- Satisfaction with Life Survey

### Analytic Plan

- Multiple linear regression models to compare modeling diagnostics (R^2, AIC, BIC)
  - No SES variables on outcomes (base model)
  - Individual-level SES variables on outcomes
  - NSDI on outcomes
  - Neighborhood:Individual NSDI residuals on outcomes
  - NSDI + individual-level SES on outcomes

### Sample

- 19,319 subjects enrolled in the TBIMS study between October 1988 and June 2022
- 6,759 Form II follow-ups had an NSDI variable assigned at 2, 5, or 10 years.
- After restricting to only the most recent follow-up for each participant with an NSDI variable, the dataset contained 4,927 participants.

Follow Up Period	N (%)
2-year follow-up	1,459 (29.6%)
5-year follow-up	1,755 (35.6%)
10-year follow-up	1,713 (34.8%)

Table 1. Summary of demographic and preinjury characteristics (n=4,927)

	Mean (St. Dev.)	Missingness
	Medii (St. Dev.)	n (%)
Age at follow up (years)		0 (0%)
Mean ± std	40.4 ± 13.1	
Median (IQR)	38 (29, 52)	
Min-Max	17-70	
Time since injury (years)		0 (0%)
Mean ± std	6.6 ± 3.7	
Median (IQR)	5.8 (2.5, 10.3)	
Min-Max	1.4-12.4	
Post-Traumatic Amnesia (days)		804 (16.3%)
Mean ± std	23.7 ± 21.4	
Median (IQR)	19 (8, 33)	
Min-Max	0-217	
	Count (04)	Missingness
	Count (%)	n (%)
Sex		2 (0.0%)
Male	3,679 (74.7%)	
Female	1,246 (25.3%)	
Race		
White	3,624 (73.6%)	40 (0.8%)
Black	861 (17.5%)	45 (0.9%)
Asian	144 (2.9%)	42 (0.9%)
American Indian/ Alaskan Native	181 (3.7%)	44 (0.9%)
Native American/ Pacific Islander	32 (0.7%)	44 (0.9%)
Ethnicity		
Hispanic	757 (15.4%)	35 (0.7%)
Follow Up Period		0 (%)
2 <u>vear</u>	1,459 (29.6%)	
5 <u>year</u>	1,755 (35.6%)	
10 <u>year</u>	1,713 (34.8%)	

## Table 2. Summary of exposure variables

	Mean (St. Dev.)	n (%)
Neighborhood Level SES Index 2019 (NSDI)		0 (0%)
Mean ± std	-0.05 ± 1.02	
Median (IQR)	-0.11 (-0.77, 0.58)	
Min-Max	-3.00-4.47	
Neighborhood: Individual NSDI residuals (continuous)		0 (0%)
Mean ± std	0.01 ± 1.01	
Median (IQR)	-0.06 (-0.65, 0.62)	
Min Max	-3.18-4.78	
Years of Education (continuous)		8 (0.1%)
Mean ± std	13.3 ± 2.6	
Median (IQR)	13 (12, 15)	
Min Max	1-21	
	Count (%)	Missingness n (%)
Annual Household Income		0 (0%)
Less than \$25,000	1,792 (36.4%)	
\$25,000-\$49,999	1,188 (24.1%)	
\$50,000-\$99,999	1,143 (23.2%)	
\$100,000-\$149,999	462 (9.4%)	
\$150,000-\$199,999	160 (3.3%)	
\$200,000 or more	182 (3.7%)	
<b>Bachelor's Degree or Higher</b>	1,112 (22.6%)	0 (0%)
Unemployment Status at Follow Up		0 (0%)
Unemployed	927 (18.8%)	
Not unemployed	4,000 (81.2%)	
Neighborhood: Individual NSDI		0 (0%)
residual quintile		0 (0%)
Very high	774 (15.7%)	
Moderately high	913 (18.5%)	
Near Zero	1,409 (28.6%)	
Moderately low	1,112 (22.6%)	
Very low	719 (14.6%)	

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### Table 3. Summary of Outcomes

	Mean (St. Dev.)	Missingness n (%)
Participation Assessment with		
Recombined Tools – Objective		<mark>1,382 (28%)</mark>
(PART-O) (Rasch)		
Mean ± std	57.2 ± 6.6	
Median (IQR)	57.3 (53.3, 61.6)	
Min-Max	31.1-89.7	
Disability Rating Scale		353 (7.1%)
Mean ± std	2.5 ± 2.9	
Median (IQR)	2 (0, 4)	
Min-Max	0-26	
Functional Independence		106 (4.0%)
Measure – Total		190 (4.0%)
Mean ± std	116.8 ± 15.8	
Median (IQR)	122 (116, 125)	
Min-Max	18-126	
Satisfaction with Life Survey –		705 (14.3%)
Mean ± std	22.1 ± 8.4	
Median (IQR)	23 (15, 29)	
Min-Max	5-35	
Satisfaction with Life Survey –		007 (14 10()
4-item		697 (14.1%)
Mean ± std	18.2 ± 6.9	
Median (IQR)	19 (13, 24)	
Min-Max	4-28	

### Table 4. PART\_RaschF Outcome (n=3,506)

Model	Model	df	F Value	P Value	Adjusted	AIC	BIC	Model	df	F Value	P Value	Adjusted	AIC	BIC
#-a	House	~	i vatac	i vatuc	R <sup>2</sup>		510	#-b°	ş	i vatue	I Value	R <sup>2</sup>	AIO	510
M1a	Intercept	0	-	-	0.0000	16732	13226	M1b	8	22.46	< 0.0001	0.0467	16573	13067
M3a	Individual-level SES variables (Ed cat)°	7	115.02	<0.0001	0.1855	16020	12514	M3b	15	71.41	<0.0001	0.2348	15824	12318
M4a	NSDI <sup>#</sup>	1	110.91	<0.0001	0.0307	16625	13119	M4b	9	32.16	<0.0001	0.0741	16472	12966
M7a	NSDI + Individual level SES variables (Ed cat)	8	100.62	<0.0001	0.1853	16022	12516	M7b	16	67.04	<0.0001	0.2316	15825	12319
M9a	Neighborhood: Individual NSDI Residuals Quintiles <sup>e</sup>	4	2.27	0.0591	0.0014	16731	13225	M9b	12	15.72	< 0.0001	0.0480	16572	13066
M12a	Neighborhood:Individual NSDI Residuals Quintiles +	11	73.17	<0.0001	0.1847	16028	12522	M12b	19	56.32	<0.0001	0.2307	15832	12326
* Model#	t-b controls for Demographic and Clinical Variables [Age at f	ollow	up (vears)	+ Time sinc	e iniury (vears	a) + Black	Race (ve	s/no) + As	ian B	ace (ves/n	o) + Pacific I	slander Race	(ves/no)	
America	n Indian Race (yes/no) + White Race (ref) + Hispanic Ethnicity	(yes/r	10) + Sex (n	nale/female	)]	. Dialok	11000 (10)	anoj • No		100 (Joon	o, aomo i		(300/110)	
° Individ	ual-Level SES Variables (Ed Cat)= Annual Household Income	e (Ref	=\$200,000)	) + Unemplo	yment Status	at Follov	v Up (yes/	(no) + Bac	helo	r's Degree (	or Higher (ye	s/no)		
d NSDI=	National Social Deprivation Index composite score													



Linear plot of PART-O Rasch and Neighborhood Socioeconomic Deprivation Index across Household Income Categories

# Type III SS analysis testing for interaction of NSDI and HHIncome on PART-O Rasch Outcome

Model #	Effects	dť	Type III SS	F Value	P Value	Model #- b	₫f	Type III SS	F Value	P Value
	SESIndex2019		131.68	3.73	0.0535			33.49	1.01	0.3160
M8a	HHIncomeF		15563.75	88.21	<0.0001	M8b		14198.24	85.27	<0.0001
	SESIndex2019*HHIncomeF		573.88	3.25	0.0062			460.98	2.77	0.0168

### Figure 2. Interaction of NSDI and Annual HH Income on PART-O Rasch estimates and CI



### Table 4. PART\_RaschF Outcome (n=3,506)

Model	Model	df	E Value	P Value	Adjusted	AIC	BIC	Model	df	E Value	D Value	Adjusted	AIC	BIC
#-a	Houet	*	i vatue	r vatue	R <sup>2</sup>	AIO	ыо	#-b°	~~	i vatue	r vatuc	R <sup>2</sup>	AIO	ыо
M1a	Intercept	0	-	-	0.0000	16732	13226	M1b	8	22.46	< 0.0001	0.0467	16573	13067
M3a	Individual-level SES variables (Ed cat)°	7	115.02	<0.0001	0.1855	16020	12514	M3b	15	71.41	<0.0001	0.2348	15824	12318
M4a	NSDI	1	110.91	<0.0001	0.0307	16625	13119	M4b	9	32.16	<0.0001	0.0741	16472	12966
M7a	NSDI + Individual level SES variables (Ed cat)	8	100.62	<0.0001	0.1853	16022	12516	M7b	16	67.04	<0.0001	0.2316	15825	12319
M8a	NSDI + Individual level SES variables (Ed cat) +	13	63.37	<0.0001	0 1879	16016	12510	M8b	21	51.87	<0.0001	0.2336	15821	12315
1100	NSDI*Household Income Interaction	.0	00.07	~0.0001	0.1075	10010	12010	1105	21	01.07	~0.0001	0.2000	10021	12010
M9a	Neighborhood: Individual NSDI Residuals Quintiles®	4	2.27	0.0591	0.0014	16731	13225	M9b	12	15.72	< 0.0001	0.0480	16572	13066
M12a	Neighborhood:Individual NSDI Residuals Quintiles +	11	73.17	< 0.0001	0.1847	16028	12522	M12h	19	56.32	< 0.0001	0.2307	15832	12326
	Individual level SES variables (Ed cat)		/0.1//	0.0001	0.1047	10020	12022	11120		00.02	0.0001	0.2007	10002	12020

\* Model#-b controls for **Demographic and Clinical Variables** [Age at follow up (years) + Time since injury (years) + Black Race (yes/no) + Asian Race (yes/no) + Pacific Islander Race (yes/no) American Indian Race (yes/no) + White Race (ref) + Hispanic Ethnicity (yes/no) + Sex (male/female)]

Individual-Level SES Variables (Ed Cat)= Annual Household Income (Ref=\$200,000) + Unemployment Status at Follow Up (yes/no) + Bachelor's Degree or Higher (yes/no)

<sup>d</sup> NSDI= National Social Deprivation Index composite score

### Table 5. DRS Outcome

Model #-a	Model	₫£	F Value	P Value	Adjusted R <sup>2</sup>	AIC	BIC	Model #-b <sup>a</sup>	₫£	F Value	P Value	Adjusted R <sup>2</sup>	AIC	BIC
M1a	Intercept	0	-	-	0.0000	14296	9770	M1b	8	16.32	< 0.0001	0.0264	14183	9657
M3a	Individual-level SES variables (Ed cat) <sup>c</sup>	7	58.24	< 0.0001	0.0813	13919	9393	M3b	15	32.08	< 0.0001	0.0934	13867	9341
M4a	NSDI <sup>d</sup>	1	84.58	< 0.0001	0.0181	14214	9688	M4b	9	18.94	< 0.0001	0.0345	14146	9620
M7a	NSDI + Individual level SES variables (Ed cat)	8	51.06	< 0.0001	0.0813	13920	9394	M7b	16	30.07	< 0.0001	0.0932	13869	9343
M8a	NSDI + Individual level SES variables (Ed cat) + NSDI*Household Income Interaction	13	32.15	<0.0001	0.0821	13921	9395	M8b	21	23.28	<0.0001	0.0937	13871	9345
M9a	Neighborhood:Individual NSDI Residuals Quintiles®	4	2.20	0.0666	0.0011	14295	9769	M9b	12	11.25	< 0.0001	0.0265	14186	9660
M12a	Neighborhood:Individual NSDI Residuals Quintiles + Individual level SES variables (Ed cat)	11	37.15	<0.0001	0.0808	13925	9400	M12b	19	25.32	<0.0001	0.0927	13875	9349
" Model#	-b controls for <b>Demographic and Clinical Variables</b> [Age at f	ollow	up (years)	+ Time since	e injury (years	s) + Black	Race (ye	s/no) + As	ian R	ace (yes/no	o) + Pacific I	slander Race	(yes/no)	
America	n Indian Race (yes/no) + White Race (ref) + Hispanic Ethnicity	(yes/r	no) + Sex (n	nale/female	)]									
° Individ	ual-Level SES Variables (Ed <u>Cat)=</u> Annual Household Income	e (Ref⊧	=\$200,000)	) + Unemplo	yment Status	at Follow	/ Up (yes/	'no) + Bac	helor	's Degree o	or Higher (ye	s/no)		
	National Casial Deprivation Index composite acore													

<sup>a</sup> NSDI= National Social Deprivation Index composite score

Model #	Effects	df	Type III SS	F Value	P Value	Model #-b	df	Type III SS	F Value	P Value
	SESIndex2019	1	0.22	0.03	0.8690		1	1.43	0.18	0.6690
M6aª	HHIncomeF	5	1376.52	34.72	<0.0001	M6b	5	1171.54	29.89	<0.0001
	SESIndex2019*HHIncomeF	5	65.05	1.64	0.1456		5	58.27	1.49	0.1906

### Table 6. FIM Outcome

Model #-a	Model	df	F Value	P Value	Adjusted R <sup>2</sup>	AIC	BIC	Model #-b <sup>a</sup>	₫£	F Value	P Value	Adjusted R <sup>2</sup>	AIC	BIC
M1a	Intercept	0	-	-	0.0000	30554	25875	M1b	8	11.73	<0.0001	0.0180	30476	25797
M3a	Individual-level SES variables (Ed cat) <sup>c</sup>	7	30.97	< 0.0001	0.0429	30355	25676	M3b	15	17.95	< 0.0001	0.0516	30321	25642
M4a	NSDI <sup>d</sup>	1	41.52	<0.0001	0.0086	30514	25835	M4b	9	12.03	<0.0001	0.0208	30464	25785
M7a	NSDI + Individual level SES variables (Ed cat)	8	27.10	<0.0001	0.0427	30357	25678	M7b	16	16.90	<0.0001	0.0516	30322	25643
M8a	NSDI + Individual level SES variables (Ed cat) + NSDI*Household Income Interaction	13	17.38	<0.0001	0.0435	30358	25679	M8b	21	13.23	<0.0001	0.0521	30324	25646
M9a	Neighborhood:Individual NSDI Residuals Quintiles®	4	3.09	0.0149	0.0018	30549	25870	M9b	12	8.54	< 0.0001	0.0190	30476	25797
M12a	Neighborhood:Individual NSDI Residuals Quintiles + Individual level SES variables (Ed cat)	11	20.14	<0.0001	0.0431	30359	25680	M12b	19	14.37	<0.0001	0.0515	30325	25646
" Model#-b controls for <b>Demographic and Clinical Variables</b> [Age at follow up (years) + Time since injury (years) + Black Race (yes/no) + Asian Race (yes/no) + Pacific Islander Race (yes/no) American Indian Race (yes/no) + White Race (ref) + Hispanic Ethnicity (yes/no) + Sex (male/female)]														

<sup>o</sup> Individual-Level SES Variables (Ed Cat)= Annual Household Income (Ref=\$200,000) + Unemployment Status at Follow Up (yes/no) + Bachelor's Degree or Higher (yes/no)

<sup>d</sup> NSDI= National Social Deprivation Index composite score

Mode #	Effects	₫f	Type III SS	F Value	P Value	Model #-b	df	Type III SS	F Value	P Value
	SESIndex2019	1	115.46	0.48	0.4889		1	275.43	1.15	0.2829
M8a	HHIncomeF	5	27442.27	22.77	<0.0001	M8b	5	22485.99	18.83	<0.0001
	SESIndex2019*HHIncomeF	5	2159.23	1.79	0.1109		5	1772.59	1.48	0.1914

### Table 7. Satisfaction with Life Survey (5-item)

Model	Model		F Value	P Value	Adjusted	AIC	BIC	Model	df	F Value	P Value	Adjusted	AIC	BIC
#-a		~~~			R²		5.0	#-b <sup>∉</sup>	~~~			R <sup>2</sup>		
M1a	Intercept	0	-	-	0.0000	21920	17743	M1b	8	18.21	<0.0001	0.0319	21792	17615
M3a	Individual-level SES variables (Ed cat) <sup>c</sup>	7	87.30	<0.0001	0.1264	21362	17185	M3b	15	48.00	< 0.0001	0.1444	21283	17106
M4a	NSDI <sup>d</sup>	1	99.19	<0.0001	0.0230	21824	17647	M4b	9	22.94	<0.0001	0.0451	21736	17559
M7a	NSDI + Individual level SES variables (Ed cat)	8	76.37	<0.0001	0.1262	21364	17187	M7b	16	45.00	<0.0001	0.1443	21285	17108
M8a	NSDI + Individual level SES variables (Ed cat) + NSDI*Household Income Interaction	13	47.32	<0.0001	0.1260	21370	17193	M8b	21	34.39	<0.0001	0.1438	21292	17116
M9a	Neighborhood:Individual NSDI Residuals Quintiles®	4	5.52	0.0002	0.0043	21906	17729	M9b	12	13.69	<0.0001	0.0352	21782	17605
M12a	Neighborhood:Individual NSDI Residuals Quintiles + Individual level SES variables (Ed cat)	11	56.19	<0.0001	0.1269	21364	17187	M12b	19	38.28	<0.0001	0.1450	21284	17108
" Model#-b controls for Demographic and Clinical Variables [Age at follow up (years) + Time since injury (years) + Black Race (yes/no) + Asian Race (yes/no) + Pacific Islander Race (yes/no)														
America	n Indian Race (yes/no) + White Race (ref) + Hispanic Ethnicity (	yes/r	10) + Sex (n	nale/female	)]									

<sup>2</sup> Individual-Level SES Variables (Ed Cat)= Annual Household Income (Ref=\$200,000) + Unemployment Status at Follow Up (yes/no) + Bachelor's Degree or Higher (yes/no)

<sup>d</sup> NSDI= National Social Deprivation Index composite score

Model #	Effects	df	Type III SS	F Value	P Value	Model #-b	df	Type III SS	F Value	P Value
M8a	SESIndex2019	1	88.59	1.45	0.2286		1	77.94	1.30	0.2539
	HHIncomeE	5	16823.13	55.08	<0.0001	M8b	5	14498.87	48.45	<0.0001
	SESIndex2019*HHIncomeF	5	263.90	0.86	0.5044		5	157.99	0.53	0.7553

### Preliminary thoughts

- Interaction model is more relevant depending on the construct
  - Won't necessarily hurt other outcomes
- Shouldn't consider individual alone or neighborhood alone
- NSDI continuous + individual factors generally performed better than the neighborhood:Individual residual groups

### To Do's

- Re-categorize education to less than HS, HS-less than BA, BA or higher (mid group as reference)
- Include PTA transformation in the models adjusted for covariates
- Change outcomes to 3 different constructs available in continuous format:
  - Participation (Keep PART-O Rasch)
  - Functional Independence (Keep DRS or FIM)
  - Subjective Well Being (Keep SWLS, change to 4-item)