

Supplementary Online Content

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This supplementary material has been provided by the authors to give readers additional information about their work.

eTable 1. Acute and Subacute Symptom Descriptions

Domain	Acute		Subacute			
		n	(%)	n	(%)	
Cognitive / Behavioral	Combined	16	(76)	Combined	19	(90)
	Desire to change location	10	(48)	Cognitive change	13	(62)
	Confusion/Disorientation	8	(38)	Memory trouble	11	(52)
	Agitation/Irritability	6	(29)	Difficulty concentrating	11	(52)
	Desire to cover head/ears	5	(24)	Word finding difficulty	11	(52)
	Fatigue	3	(14)	Fatigue	10	(48)
	Feeling of paralysis	3	(14)	Agitation/Irritability	8	(38)
				Increased time for cognitive tasks	7	(33)
				Errors at work	6	(29)
Balance / Vestibular	Combined	10	(48)	Combined	14	(67)
	Nausea	7	(33)	Dizziness	13	(62)
	Dizziness	5	(24)	Falls	4	(19)
			Nausea	3	(14)	
Visual	Combined	2	(10)	Combined	14	(67)
	Visual changes	1	(5)	Visual changes	10	(48)
	Eye pain	1	(5)	Light sensitivity	9	(43)
				Eye strain	7	(33)
			Difficulty focusing vision	6	(29)	
Auditory	Combined	10	(48)	Combined	15	(71)
	Ear pain	7	(33)	Tinnitus	12	(57)
	Tinnitus	6	(29)	Hearing change	7	(33)
	Hearing change	1	(5)	Noise sensitivity	5	(24)
			Ear pain	5	(24)	
Sleep	Sleep problem	4	(19)	Sleep problem	16	(76)
Headache	Combined	11	(50)	Combined	17	(81)
	Headache	8	(38)	Headache	17	(81)
	Head Pressure	5	(24)	Unilateral jaw pain	2	(10)
	Unilateral jaw pain	1	(5)			
Overall	Combined acute	21	(100)	Combined subacute	21	(100)
<p>Acute – during or hours following exposure, Subacute – days to weeks following exposure Developed from patient descriptions of symptoms in acute and subacute period following exposure during evaluations at the University of Pennsylvania. Clinical interviews were open-ended, therefore lack of a particular symptom was not systematically verified</p>						

eTable 2. Neuropsychological Test Results: Cognitive Domains (n=6)

	Case					
	4	9	11	13	15	20
Auditory Attention and Working Memory						
Digit Span Forward	50	84	9	91	50	98
Digit Span Backward	63	63	50	95	16	95
Digit Span Sequencing	37	37	50	95	37	75
Arithmetic	91	50	37	98	25	75
Letter-Number Sequencing	63	50	63	99	37	50
Visual Working Memory						
Symbol Span	63	50	84	75	63	95
Auditory and Visual Memory						
Logical Memory I	84	9	75	91	50	50
Logical Memory II	63	16	37	95	50	50
Verbal Paired Associates I	95	37	91	98	63	63
Verbal Paired Associates II	91	37	91	95	50	50
Designs I	91	9	50	84	91	84
Designs II	91	25	63	91	75	75
Visual Reproduction I	75	50	25	98	16	63
Visual Reproduction II	91	36	75	95	25	50
Rey-Osterrieth Complex Figure: 3-minute delay	95	15	<10	65	40	<10
California Verbal Learning Test – II: Trials 1 – 5	84	88	84	97	95	95
California Verbal Learning Test – II: Long Delay	63	84	50	94	25	<1
Visual-Spatial Perception and Visual-Motor Construction						
Judgment of Line Orientation	>86	72	56	>86	40	2
Rey-Osterrieth Complex Figure - copy	100	<10	<10	20	90	60
Block Design	91	63	16	91	75	75
Motor Functions						
Grooved Pegboard: Dominant	44	16	<1	88	19	<1
Grooved Pegboard: Non-Dominant	30	16	2	88	9	50
Language Functioning						
Boston Diagnostic Aphasia Examination: Boston Naming Test	88	50	19	7	25	65
Boston Diagnostic Aphasia Examination: Complex Ideational Material	58	50	19	50	50	50
Vocabulary	63	63	75	84	63	75
Executive Functions						
Controlled Oral Word Association: FAS	96	39	88	9	58	96
Animal Naming	58	55	19	4	60	60
Trail Making Test: Part A	21	65	88	82	97	<1
Trail Making Test: Part B	25	34	19	30	65	<1
Ruff Figural Fluency Test: Total Designs	61	32	29	81	21	59
Ruff Figural Fluency Test: Perseverative Errors	63	64	19	52	63	63
Processing Speed						
Coding	63	37	37	91	84	16
Symbol Search	63	25	63	37	84	2
Academic Achievement						
Wide Range Achievement Test-4, Word Reading	47	50	61	68	63	61
Reasoning						
Similarities	63	63	37	95	50	84
Matrix Reasoning	84	75	50	75	75	63
Visual Puzzles	95	84	5	98	63	75

Percentile scores shown. Bold highlighting denotes abnormality or <40th percentile¹⁻³

Table 3. Neuropsychological Test Results: Effort Testing (n=6)

	Case					
	4	9	11	13	15	20
Effort						
Test of Memory Malingering						
Trial 1	50	50	50	50	42	41
Trial 2	50	50	50	50	50	50
Rey 15-Item Visual Memory Test	15	15	15	15	12	15
<i>Values listed are all raw values, not percentiles</i>						
- For the Test of Memory Malingering, ⁴⁻⁶ normal is >26 on trial 1 and >45 on Trial 2						
- For Rey 15-Item Visual Memory Test, ⁷⁻¹¹ a score of <9 is interpreted as a lack of effort						

Table 4. Neuropsychological Test Results: Mood Functioning (n=6)

	Case					
	4	9	11	13	15	20
Mood Functioning¹²⁻¹⁷						
Beck Depression Inventory-II	3	17	24	12	11	16
	(Min)	(Mild)	(Mod)	(Min)	(Min)	(Mild)
Beck Anxiety Inventory-Revised	2	2	14	10	5	10
	(Min)	(Min)	(Mild)	(Mild)	(Min)	(Mild)
Brief Mood Survey						
Depression	0	2	7	3	3	3
		(Bord)	(Mod)	(Mild)	(Mild)	(Mild)
Suicidal Urges	0	0	0	0	0	0
Anxiety	1	3	11	3	4	5
	(Bord)	(Mild)	(Severe)	(Mild)	(Mild)	(Mild)
Panic	ND	0	2	1	ND	0
			(Bord)	(Bord)		
Anger	1	11	13	4	4	4
	(Bord)	(Severe)	(Severe)	(Mild)	(Mild)	(Mild)
Post-Traumatic Stress Disorder Checklist - 5 (Cutoff score 33)	1	36	49	23	16	23
Frontal Systems Behavior Scale (Before/After Injury)						
Apathy	41/46	43/77	53/92	47/69	42/68	48/66
Disinhibition	36/44	57/67	49/55	50/66	39/43	37/45
Executive Dysfunction	41/45	39/67	41/76	44/56	46/68	47/75
Total	37/44	44/74	47/74	46/64	41/62	43/65
<i>Values listed are all raw values, not percentiles</i>						
<i>Bold highlighting denotes abnormality</i>						
Abbreviations: Minimal (Min), Borderline (Bord), Not done (ND)						

eTable 5. Standardized Measures Obtained During Initial Vestibular Physical Therapy Evaluation

Case	Self-Reported Measures		Objective Measures		
	DHI	ABC	FGA	BESS	SOT
1	38	---	29	39	41
2	18	90	29	7	78
4	38	84	28	24	71
5	38	84	23	30	59
6	50	64	20	42	78
8	10	88	29	30	45
9	24	76	27	41	43
10	56	76	24	34	73
11	60	76	28	23	52
12	---	---	30	16	68
13	26	86	21	30	48
15	20	---	29	16	61
16	24	93	25	50	UTC
17	58	61	18	UTC	UTC
18	30	88	30	14	45
20	60	79	29	41	20
21	18	86	26	29	56

Normative values

- DHI¹⁸: Mild (0-30), Moderate (31-60), Severe (61-100) vestibular dysfunction
- ABC¹⁹: Score < 67% indicates a risk of falling
- FGA²⁰: Normal is 30/30
- BESS²¹: Normative values used based on Iverson et al 2013²², yielding a categories (superior, above average, broadly normal, below average, poor, and very poor) based on age and sex. Scored 0-60, with higher scores indicating increased static balance impairment.
- SOT²³: Cut off was 70 for equilibrium score for all patients in the age group tested
- **Bold highlighting denotes abnormality**
- Abbreviations: Dizziness Handicap Index (DHI); Activities Balance Confidence Scale (ABC); Functional Gait Assessment (FGA); Balance Error Scoring System (BESS); Neurocom Balance Manager Sensory Organization test (SOT), Unable to complete(UTC)

eTable 6. Caloric Testing Results

Case	Cool		Warm		RVR*	
	Right	Left	Right	Left	%	R/L
1	35	33				
5	23	20				
8	34	22	27	24	7	L
9	20	20				
10	9	3	12	4	50	L
11	24	13	19	7	37	L
13	12	22	22	28		
15	28	17	38	20	28	L
16	39	48	51	62	10	R
17	18	22				
18	19	20				
20	37	8	63	12	67	L
21	42	35				

Normal Values: RVR threshold is <25% asymmetry. Above 25% asymmetry is diagnostic for a unilateral peripheral vestibular lesion.²⁴⁻²⁶
 - *Bold highlighting denotes abnormality*
 - Abbreviation: Relative Vestibular Reduction (RVR)
 - Evaluation of warm caloric and RVR only indicated when asymmetry observed with cool caloric per standard audiology practice.

eTable 7. Vestibular Impairments Identified Requiring Rehabilitation Interventions

Case	Static Balance	Dynamic Balance	VOR ⁺ Impairment	Unilateral Peripheral Vestibular Impairment
1	X	X	X	
2		X	X	NT
4	X	X		NT
5	X	X	X	
6	X	X	X	NT
8	X	X	X	
9	X	X	X	
10	X	X	X	X
11	X	X	X	X
12	X			NT
13	X	X	X	
15	X	X	X	X
16	X	X	X	
17	X	X	X	
18	X	X	X	
20	X	X	X	X
21	X	X	X	
n	16	16	15	4
(%)	(76)	(76)	(71)	(31)*
+ Vestibulo-ocular reflex (VOR)				
*Percentage is based on 13 individuals who underwent caloric evaluation				
Abbreviations: Not tested (NT)				

eTable 8. Standardized Measures Obtained During Initial Neuro-Optometry Evaluation

Case	Self-Reported Measure	Objective Measures			
	CISS*	NPC (cm)		PFV (PD)	DEM (sec)
		Break	Recovery		
1	40	7.5	13	35	29
2	---	2.5	5	25	25
4	---	2.5	5	25	32
5	76	13	20	12	40
6	---	10	15	30	27
9	40	12	23	20	53
10	---	4	7.5	40	27
11	74	7.5	13	16	58
13	51	10	15	18	40
14	---	5	7.5	30	50
15	46	13	25	6	40
16	77	7.5	15	30	74
17	67	25	40	18	67
18	---	5	8	18	38
20	57	7.5	30	6	90

Normative values
 - Abnormal CISS²⁷ is ≥ 16
 - Abnormal NPC^{28,29} is ≥ 6 cm break and ≥ 8 cm for Recovery
 - Abnormal PFV^{28,29} ≤ 20 prism diapters (PD) base out.
 - Abnormal DEM^{28,30} is ≥ 30 seconds
 - **Bold highlighting denotes abnormality**
 -Abbreviations: Convergence Insufficiency Symptom Survey (CISS); Near Point of Convergence (NPC); Positive Fusional Vergence (PFV); Prism Diopters (PD); Developmental Eye Movement Test (DEM)
 * CISS obtained at initiation of neuro-optometric rehabilitation when indicated per standard neuro-optometry practice.

eTable 9. Clinically Significant Oculomotor Impairments Identified Requiring Dedicated Neuro-optometric Rehabilitation (n=11)

Case	Convergence Insufficiency	Accommodative Insufficiency	Saccadic Dysfunction	Pursuit Dysfunction	Photophobia
1	X	*		X	X
5	X	*	X	X	X
6	X			X	X
9	X	*	X		
11	X	X	X	X	X
13	X	*	X	X	X
15	X	*	X	X	X
16	X	X	X	X	X
17	X	*	X	X	X
18	X		X	X	
20	X	*	X	X	X
n	11	2	9	10	9
(%)	(100)	(18)	(82)	(91)	(82)
<p>*Measurements consistent with accommodative insufficiency and historical description of visual change after exposure, however formal diagnosis limited over the age of 40 due to age-appropriate presbyopia. -clinical diagnosis of convergence insufficiency, accommodative insufficiency, saccadic and pursuit dysfunction, and photophobia was performed according to the standards detailed in the methods section, and included integration of standardized measures along with expert clinical evaluation. -of the 4 individuals listed in Table 1 above that did not require formal Neuro-optometric rehabilitation at Penn, one received neuro-optometric rehabilitation after exposure but prior to Penn evaluation, two had oculomotor exercises integrated into vestibular and/or occupational therapy, and was provided a home exercise program.</p>					

eTable 10. Pure Tone Audiometry Results

Case		Frequency (Hz)								Hearing Level in dB	
		250	500	1000	1500	2000	3000	4000	6000		8000
1	R	10	15	10		15	10	10	15	15	
	L	10	10	10		5	10	10	15	15	
5*	R	15	15	20		20	25	15	5	10	
	L	15	15	20		20	20	15	5	5	
8	R	10	5	5		10	10	5	10	10	
	L	15	10	5		10	15	15	10	5	
9†	R	10	5	5		10	40	45	30	20	
	L	15	5	10		10	55	35	20	10	
10‡	R	5	10	5		15	30	15	5	20	
	L	30	35	40	50	55	55	60	75	95	
11‡	R	15	15	15		10	15	10	15	5	
	L	50	40	35		30	30	25	25	10	
13§	R	15	15	10		10	15	10	25	20	
	L	20	20	15		15	20	25	35	30	
15	R	5	5	15		10	15	20	20	15	
	L	5	15	10		20	15	20	20	20	
16	R	20	20	15		20	15	15	15	20	
	L	10	15	15		15	15	15	15	15	
17§	R	15	20	15		20	25	25	20	15	
	L	20	20	20		10	15	25	20	15	
18	R	5	10	10		5	10	5	10	10	
	L	10	10	5		10	15	10	15	15	
20‡	R	50	45	45	40	25	25	25	25	20	
	L	45	45	40	35	25	25	20	25	20	
21	R	10	15	5		10	5	5	10	10	
	L	15	15	15		10	10	5	10	10	

-Results from Pure Tone Audiometry performed as part of a comprehensive audiological assessment which included Speech Audiometry
- NOTE: of the 4 cases with sensorineural hearing loss (SNHL) above (9,10, 11, 20), none of the individuals report noticing or being diagnosed with hearing loss prior to exposure. One individual did report frequent ear infections as a child, though reported normal functional hearing until exposure.
- normal is <=20 dB at each frequency.
- **Bold highlighting denotes abnormality**
* Case 5: isolated impairment with unclear clinical relevance.
† Case 9: mild to moderate SNHL, no hearing aid indicated.
‡ Cases 10, 11, and 20: moderate to severe SNHL, received hearing aid.
§ Cases 13 and 17: borderline to mild SNHL, no hearing aid indicated.

eTable 11. Sleep and Headache Medication Requirements

Case	Impaired Sleep		Headache		Specific Medications Used Included:																																													
	Subjective Complaint	Medication Required	Subjective Complaint	Medication Required																																														
1	X	X			<table border="0"> <tr> <td colspan="2">Headache Medications</td> <td>N</td> </tr> <tr> <td>Acetaminophen/Aspirin/Caffeine</td> <td></td> <td>8</td> </tr> <tr> <td>Rizatriptan</td> <td></td> <td>5</td> </tr> <tr> <td>Sumatriptan</td> <td></td> <td>1</td> </tr> <tr> <td>Butalbital/Acetaminophen/Caffeine</td> <td></td> <td>1</td> </tr> <tr> <td>Gabapentin</td> <td></td> <td>4</td> </tr> <tr> <td>Propranolol</td> <td></td> <td>2</td> </tr> <tr> <td>Topiramate</td> <td></td> <td>1</td> </tr> <tr> <td>Amitriptyline</td> <td></td> <td>1</td> </tr> <tr> <td>Riboflavin</td> <td></td> <td>2</td> </tr> <tr> <td colspan="2">Sleep Medications</td> <td>N</td> </tr> <tr> <td>Melatonin</td> <td></td> <td>10</td> </tr> <tr> <td>Doxepin</td> <td></td> <td>6</td> </tr> <tr> <td>Gabapentin</td> <td></td> <td>6</td> </tr> <tr> <td>Trazodone</td> <td></td> <td>3</td> </tr> </table>	Headache Medications		N	Acetaminophen/Aspirin/Caffeine		8	Rizatriptan		5	Sumatriptan		1	Butalbital/Acetaminophen/Caffeine		1	Gabapentin		4	Propranolol		2	Topiramate		1	Amitriptyline		1	Riboflavin		2	Sleep Medications		N	Melatonin		10	Doxepin		6	Gabapentin		6	Trazodone		3
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Propranolol		2																																																
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4																																																		
5	X	X	X	X																																														
6	X	X	X	X																																														
7	X	X																																																
8	X	X	X																																															
9	X	X	X	X																																														
10	X		X	X																																														
11	X	X	X	X																																														
12	X		X	X																																														
13	X	X	X	X																																														
14	X	X	X																																															
15	X	X	X	X																																														
16	X	X	X	X																																														
17	X	X	X	X																																														
18	X	X	X	X																																														
19																																																		
20	X	X	X	X																																														
21	X	X	X																																															
n	18	15	16	12	Medications were selected based on clinical indication, efficacy, and tolerance, and were adjusted as clinically indicated. Efforts were made to minimize cognitive side effects																																													
(%)	(86)	(71)	(76)	(57)																																														

eAppendix. Glossary of Terms

Activities Balance Confidence Scale^{19,31} (ABC): is a widely used self-reported standardized measure which asks a patient to rate their perceived confidence in performing various mobility / movement tasks without a loss of balance or fall. A score of < 67% on this measure indicates that the patient is at risk of falling.

Balance Error Scoring System^{21,22} (BESS): a standardized test of static balance, which evaluates the ability to maintain stability while performing double limb stance, non-dominant single limb stance, and tandem stance, each on both a firm surface and on foam. Scoring ranges from 0-60, with normative categories (superior, above average, broadly normal, below average, poor, and very poor) based on age and sex.

Caloric Reflex Testing²⁴⁻²⁶: Standardized test to evaluate peripheral vestibular end organs, and the clinical gold-standard test identifying a unilateral peripheral vestibulopathy. Interpretation of caloric testing is done by looking at the Relative Vestibular Reduction (RVR) percentage, with an RVR of > 25% asymmetry being diagnostic for a unilateral peripheral vestibular lesion.

Clinical Test of Sensory Organization and Balance^{32,33} (CTSIB): a non-instrumented, quantitative method of evaluating postural control in different sensory conditions.

Computerized Dynamic Posturography²³ (CDP): an instrumented method of quantitating balance functioning. This case series utilized the Sensory Organization Test, a form of CDP, which quantitates the use of visual, proprioceptive, and vestibular cues to maintain postural stability. Given the age group of this case series, a cut off value of 70 for equilibrium score was used to define pathology.

Convergence Insufficiency Symptom Survey²⁷ (CISS): a self-reported measure used to quantify symptoms related to convergence insufficiency and oculomotor dysfunction, and to track symptom

improvement throughout neuro-optometric rehabilitation. Abnormal CISS is ≥ 16 , and indications ongoing symptoms related to convergence insufficiency and/or oculomotor dysfunction.

Developmental Eye Movement Test^{28,30} (DEM): a timed visual-verbal test used to evaluate saccadic eye movement speed and accuracy. Abnormal DEM performance time is ≥ 30 seconds, and indicates dysfunction of saccadic eye movements.

Directional Phenomena: a term used throughout the manuscript to describe the perception of sound, pressure, and/or vibration emanating from a distinct direction in space.

Dizziness Handicap Index¹⁸ (DHI): a standardized measure of perceived impairment related to dizziness, which correlates with vestibular dysfunction: Scoring ranges between mild (0-30), Moderate (31-60), and Severe (61-100) impairment.

Dynamic Balance: the ability to maintain postural orientation and postural stability while the body is in motion (ex. walking, running). This is often measured using the Functional Gait Assessment (see below).

Functional Gait Assessment²⁰ (FGA): is a standardized measure used to identify abnormalities in dynamic balance. There are 10 gait conditions (gait with: level surfaces, change gait speed, horizontal head movements, vertical head movements, pivot turns, stepping over an obstacle, narrow base of support (tandem gait), eyes closed, and ambulating backwards) which are each scored from 0 to 3 (0= severe impairment, 1= moderate impairment, 2= mild impairment, 3=normal). Normative score of 30/30.

Near Point of Convergence^{28,29} (NPC): the closest distance (in cm) at which the patient is no longer able to maintain single vision. It is measured from the brow above the nose and represents the maximum

total convergence response. Target is a small letter on a tongue depressor or a penlight. Normative cut-off is 6 cm.

Neuropsychological Testing / Battery:¹⁻¹⁷ A comprehensive assessment of cognitive, neurobehavioral and mood functioning that is performed by a highly trained neuropsychologist. Neuropsychological evaluations typically last for multiple hours, consisting of a thorough clinical interview (e.g., basic demographic information including family, educational and employment history, as well as environmental event details), self-reported symptoms, mood inventories, and extensive objective testing of cognitive domains (e.g., executive functioning, memory, attention, working memory, visual-spatial perception, visual-motor construction, motor functioning, language, reasoning, processing speed, academic functioning).

Positive Fusional Vergence^{28,29} (PFV) [also known as fusional convergence]: the maximum amount of disparity vergence measured with prisms before a patient reports blur or diplopia. Test distance is 40 cm and normative cut-off is 20 prism diopters base out.

Static Balance: the ability to maintain both postural orientation and postural stability while standing still. Static balance is assessed in under multiple conditions, including firm surfaces, unstable surfaces (Ex. foam), both with eyes open and eyes closed.

Vestibulo-ocular reflex²⁵ (VOR): a complex neurologic reflex that coordinates eye and head movements to maintain focus on a visual target.

Vestibular / Ocular-Motor Screening³⁴ (VOMS): standardized measure to quantify symptomatic responses to clinical vestibular and oculomotor testing, specifically evaluation of saccadic eye movements, smooth pursuits, vergence, VOR, and visual motion sensitivity.

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