

● INVITED REVIEW

Post electrical or lightning injury syndrome: a proposal for an American Psychiatric Association's Diagnostic and Statistical Manual formulation with implications for treatment

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Abstract

In the past, victims of electrical and lightning injuries have been assessed in a manner lacking a systematic formulation, and against *ad hoc* criteria, particularly in the area of neuropsychological disability. In this manner patients have, for example, only been partially treated, been poorly or incorrectly diagnosed, and have been denied the full benefit of compensation for their injuries. This paper contains a proposal for diagnostic criteria particularly for the neuropsychological aspects of the post injury syndrome. It pays attention to widely published consistent descriptions of the syndrome, and a new cluster analysis of post electrical injury patients. It formulates a proposal which could be incorporated into future editions of the American Psychiatric Association's Diagnostic and Statistical Manual (DSM). The major neuropsychological consequences include neurocognitive dysfunction, and memory subgroup dysfunction, with ongoing consequences, and sometimes including progressive or delayed psychiatric, cognitive, and/or neurological symptoms. The proposed diagnostic criteria insist on a demonstrated context for the injury, both specifying the shock circumstance, and also physical consequences. It allows for a certain delay in onset of symptoms. It recognizes exclusory conditions. The outcome is a proposal for a DSM classification for the post electrical or lightning injury syndrome. This proposal is considered important for grounding patient treatment, and for further treatment trials. Options for treatment in electrical or lightning injury are summarised, and future trials are foreshadowed.

Key Words: electrical injury; lightning injury; neuropsychology; neuropsychiatry; injury; American Psychiatric Association's Diagnostic and Statistical Manual

Introduction

Electrical injury (EI) and lightning injury (LI), while mechanistically different injuries, have certain features in common including the neuropsychiatric syndrome following the injury. (The term "electrocution" is often used to describe the injury due to contact with electric current. This term, however, implies death from the event. We prefer to say that the victim has been the subject of injury from electric current, or has had an electric current injury.) It has been extensively explored and described (Draper, 1937; Shaw and York Moore, 1957; Daniel et al., 1985; Cooper et al., 1992; Engelstatter, 1993; Cooper, 1994; Kelley et al., 1994; Pliskin et al., 1994; Primeau et al., 1995a, b; Janus and Barrash, 1996; Crews et al., 1997; Pliskin et al., 1998, 1999, 2006; Duff and McCaffrey, 2001; Andrews, 2003, 2012, 2014; Martin et al., 2003; Cochran et al., 2004; Morse et al., 2004; Primeau, 2005; Reisner, 2006, 2013, 2014; Bailer et al., 2008; Chudasama et al., 2010). A recent review collated and documented these descriptions comprehensively, and proposed causative mechanisms (Andrews and Reisner, 2017) for this enigmatic syndrome.

These papers describe the sequelae of electrical or lightning

injury (ELI). The sequelae may include losses in physical work ability and similar work related functions, loss of cognitive ability, depression, phobic withdrawal, loss of memory, initiative, and concentration, loss of learning and development ability, reliance on workmates, loss of promotion, and eventually loss of employability. In the domestic environment, there is then inability to support a family, loss of income and opportunity, inability to partake in family activities, inability to enjoy usual hobbies, inability to partake of family social life, and personality change leading to relationship disturbance, and often relationship breakdown. The loss of self-image is profound and may lead to self-isolation, self-medication if appropriate medical care is unavailable, depression, and ultimately, thoughts of suicide.

The neuropsychiatric consequences of the injury are thus significantly disabling and constitute some of the greatest impediments to resuming useful employment and daily work function, along with relationship and social function (Cooper, 2001). These injuries are often poorly recognized, despite their extensive documentation, and are often passed over as, at best, transitory, or at worst malingering. In contrast, Martin et al. (2003) state that at

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five years after EI, in their study, psychiatric deterioration had occurred and, “the majority of patients had lost their jobs.”

This paper concentrates on the neuropsychiatric symptoms and signs in ELI. It sets out to establish a firm basis to diagnose the post injury syndrome.

Prevalence and Morbidity in ELI

While ELI can have devastating immediate and progressive consequences, it is not assumed that every person subject to electrical or lightning shock will develop these severe symptoms. In fact, having a formal diagnosis for the post electrical and lightning injury syndrome (PELIS) will allow future clinical research to determine what percentage of victims develop these syndromes and under what conditions.

Nonetheless, some important morbidity prevalence data, particularly involving EI, is available. One group of authors (Kelley et al., 1999) cited a study which found that 96.7% of professional electricians surveyed had received an electrical shock, but only 11% of them sought medical attention. In this study, 92% of those experiencing loss of consciousness sought medical help, but only 32% who experienced being “thrown away” from an electrical contact went to a hospital, and 52% who experienced a “no-let-go” episode after electrical contact, went to the hospital (Tkachenko et al., 1999). Of studies of electrical injuries wherein the individual sought medical attention, the prevalence of significant psychiatric diagnoses (depression, anxiety, and/or PTSD) ranged between 57.5% (Kelley et al., 1999) and 87.5% (Hooshmand, 1989). A study discussed in detail below found a total of 78% of electrical injury patients had one or two subsequent psychiatric diagnoses (Ramati et al., 2009b). It can be inferred strongly that a high percentage of EI patients have psychiatric sequelae. But there are many individuals (at least professional electricians) who receive shocks but never present for evaluation and treatment. At minimum, the proposed diagnosis of PELIS will have the most relevance among the subset of individuals who do seek medical treatment, but may also be instrumental in encouraging more victims to seek help.

An assessment of 86 consecutive electrical injury patients who presented to the Electrical Trauma Research Program (ETP), an academic/medical research program located in the Chicago, IL, USA has been made (Ramati et al., 2009b). As part of the assessment process, each patient was evaluated by a psychiatrist as well as a neuropsychologist. The results with regard to psychiatric morbidity indicated: “Seventy-eight percent of the total sample of EI subjects warranted a psychiatric diagnosis based on their evaluation. Of those with a psychiatric diagnosis, 52% had a single psychiatric diagnosis and 26% had two psychiatric diagnoses” (p. 363). A crucial finding of this study was that no evidence of malingering was found.

A further cohort was considered by one author (CJA). In neuropsychological testing an index measuring the likelihood of dissimulation (malingering) was reported. No results were positive. It seems a confident assertion that malingering is unlikely.

EI patients demonstrate significant psychiatric symptoms and tend to display more psychiatric disturbance with increasing time from the trauma (seen up to two years post-injury, of those who entered post-acute treatment/assessment) (Ramati et al., 2009b). It was noted that history of a previous psychiatric diagnosis (pre-injury), previous psychiatric medication usage, reported voltage level, current pain level, pain medication usage, and litigation status “were *not* significant predictors of psychiatric morbidity” (p.

364) (*present authors’ emphasis*).

The most common psychiatric diagnoses applied were adjustment disorders, depression and posttraumatic stress disorder (PTSD). The patients who had two or more psychiatric diagnoses post-injury also displayed the most cognitive deficits in verbal memory, executive functioning, and attention. These researchers (Ramati et al., 2009b) cited a study indicating that 2,287 US workers died and over 32,000 workers sustained days away from work due to EI between 1992 and 1998 (Cawley and Homce, 2003). Even though there may be many individuals who receive an electrical shock and do not seek treatment, in these figures there are clearly many people adversely affected by electrical injury and its consequences. Among those who seek medical attention, significant psychiatric morbidity is noted (Ramati et al., 2009b). More systematic research is needed in the area of prevalence of morbidity for electrical injury, and this is especially needed in the area of lightning injury.

Lightning is a powerful force which can cause death and disability. It has been estimated that there have been between 75 to 150 deaths per year in the United States resulting from lightning strike (Davidson and Deck, 1988; Duff and McCaffrey, 2001). This was a previous estimate, and the present rate of documented deaths for the past decade is 31/year. The reduction may well be due to the introduction of significant lightning awareness and safety programmes (for example, <http://www.lightningsafety.noaa.gov/fatalities.shtml> and also (Cooper and Ab Kadir, 2010; Lengyel et al., 2010; Cooper and Holle, 2012)). Another source noted that between 1959 and 1994 there were over 3,000 deaths resulting from lightning strike, and 10,000 “casualties” (Cherington, 2005b). Cooper and Andrews (2003) state: “Only about 10% of people who are struck by lightning are killed, leaving 90% with various degrees of disability.”

It has been noted that with both electrical and lightning injury, the sequelae can range from “minimal” to “severe” (Duff and McCaffrey, 2001). The spectrum of relatively serious or severe psychiatric, neuropsychological and neurological sequelae of lightning injury has been well described (Duff and McCaffrey, 2001; Cherington, 2005a, b; Andrews and Reiser, 2017). Perhaps because it is difficult to assemble a large sample of lightning injury patients in any one study, what appears to be missing in the literature is a clear percentage (prevalence) of patients struck by lightning who develop serious or severe sequelae. Given the expected lower overall frequency of lightning injury as compared to electrical injury, it is more difficult to study a large cohort of lightning injury patients. Whereas the previously cited study (Ramati et al., 2009b) provided an excellent and detailed study of prevalence of psychiatric morbidity of 86 consecutive EI patients evaluated over a 10 year period in a prominent research program, lightning injury patients were not included in this study, although lightning survivors were seen by the program and included in fMRI investigations (Ramati et al., 2009a). There are simply more cases of electrical injury than lightning injury in developed countries. This may create a difficulty in quantifying the prevalence of the various types of disorders and disabilities, even though the existence of these post-lightning injury disorders has been well documented. Further prevalence research is needed.

Impediments to Diagnosis

The present authors (especially CJA and MAC) have extensive

experience in assessing and characterizing the injury. It is noteworthy that there is a commonality between the neuropsychological presentations of victims of ELI, and the common features are exhibited without any possibility of collusion between subjects. The consequences often come to light in the context of diagnosis, evaluation, and management, and also for return-to-work assessment, for Workers Compensation purposes, or possibly for litigation. It is one writer's experience [CJA] that the state of the victim, in totality, deteriorates for 18–24 months following the injury, then improves to achieve stability 2–5 years from the injury, though falling short of the premorbid state.

Victims are often done a substantial disservice when the extent and the disabling effect of ELI is not recognized. There are several reasons for this. Often well-meant, though incorrect, advice is given despite lack of knowledge or experience with these patients or due to constraints of formal patient assessment and reporting.

An important constraint in formulation of an accurate diagnosis is that experts in their own specialties are constrained by existing and known diagnoses in their fields. For example, reports almost universally draw attention to a PTSD-like syndrome, and attest to its severity. There is no argument with this *as a portion* of the injury. The more realistic alternative is that the patient's presentation should be reported as a presentation that goes beyond current formalized knowledge. There is a reluctance to do this in some cases, however, possibly for reasons of justifiability in a legal context in some jurisdictions. For example, in psychiatric terms, one will see PTSD diagnosed, and also syndromes like adjustment disorder, rather than the more complete diagnosis of a syndrome seen after ELI. While this is understandable, it should not dissuade a reporter from recognizing the wider context. It is hardly surprising that ELI should give rise to a trauma response or be something to which a victim has difficulty adjusting. It is important to guard against diagnosing something like PTSD as the prime disorder rather than a specific physical and psychological response to electric current, especially since there is evidence that the response includes strong organic elements.

Physicians in a particular discipline, are limited in diagnoses by the criteria currently existing within that discipline, *e.g.*, in psychiatry, the DSM-V. There is, in fact, more to ELI than the present diagnostic framework allows. Thus, the diagnoses which are given are usually "as close as we can get" while remaining constrained by present criteria, but not stated as such. These approximations to diagnoses should not be regarded as final or complete. There is a great need to expand diagnostic criteria to include a more accurate and complete "post ELI syndrome", which we refer to as PELIS.

Formal diagnostic categories are essential, not only for definition and legal ramifications, but also for use in future clinical and epidemiological research. In research to determine what medications or treatments may help victims of PELIS, researchers must be able to separate those who suffer from these conditions from those who do not. It is also essential to determine the prevalence and percentage of individuals who receive electrical or lightning injury who go on to develop PELIS.

Towards a DSM Formulation

While the discussion above demonstrates the substantial prevalence of psychiatric morbidity, hitherto downplayed or unrec-

ognized, there is a need to define the syndrome and its specific description.

This paper, in the desire to establish a classification for PELIS, takes the cohort described previously (Andrews, 2006) and submits the cohort to Cluster Analysis (Sokal and Sneath, 1963; Clifford and Stephenson, 1975). The aim of any Cluster Analysis is to identify groups which are most alike in their character. This technique is used to produce clusters of patients and identify similarity groups by symptoms and signs. In this manner, subgroups can be identified. This, however, is beside the main focus of this paper. Cluster Analysis allows identification of the most common and significant overall symptoms and their juxtapositions, and these can then be used to establish and support the diagnostic criteria.

In the analysis, each patient was described by their own self-reported symptoms as well as by the results of neuropsychological testing. Self-reported symptoms define individual perceptions of the overall process. Being subjective does not detract from their validity, but they refine to more exact descriptions in later neuropsychological examination. For example, the self-reported "loss of mental power" may actually be a subjective description of concurrent loss of attention span, loss of concentration ability, processing speed, auditory learning deficit, and so on. This analysis combines the patient's subjective assessment with objective testing assessment.

A total of 26 patients were included. While this is only a moderate number, it is a well characterised cohort, and is considered to be well representative of the injured population. The analysis used the standard technique of Euclidean Distance estimation between individual patients over the full set of symptoms, followed by clustering based on Group Average sorting.

The cluster analysis identified two major groups of patients, G1 and G2, and these are shown in **Table 1**. At a lower level these were subdivided by the analysis into two groups each, and these groups were identified as G1A, G1B, and G2A and G2B. In **Table 1**, the G1 totals are displayed, together with the division between G1A and G1B. Similarly, for G2. There was also a Group 3 which was in fact a "split-off" a single patient and as this group was a group of only one patient, it is ignored below. This splitting is a common occurrence in cluster analysis. In any case, the symptoms associated with this individual do not define any new characteristics in our ultimate identification of the diagnostic criteria.

In broad terms, G1 can be regarded as the more severely injured of the two major groups, with G1B more so than G1A. The patients in G1 were more likely to self-report problems and thus can be considered to perceive they are more unwell. G2 as a group show fewer self-reported symptoms, however neuropsychological testing still indicates disability. G2A demonstrates more disability on testing than does G2B. Both G2 subgroups therefore demonstrate disability.

The groups are described in more detail as follows.

G1 as a whole (Gp1A - 10; Gp1B - 6)

Considering G1 as a whole, **Table 1** is shaded in column G1 where the incidence of a symptom is at least 50% of the cohort in the whole group.

In self-reported findings, remembering the subjective nature of the individual's report, the following are most pervasive:

- General memory deficit (15/16)
- Loss of "Mental Powers" (12/16)
- Deficit in Concentration (11/16)
- Aggression (10/16)

Electrical Phobia (9/16)
 These are refined in the neuropsychological testing to include:

- Auditory Memory Deficit (10/16)
- Processing Speed Deficit (10/16)
- Vocabulary and Word Finding Deficit, and Verbal Learning Deficit (9/16)

The focus on executive function is noted. Further, the presentation is refined in more detail when the subgroups are considered. The subgrouping may indicate in which group a particular feature predominantly appears. The subgroups are separately itemised below.

Group G1A

Group G1A indicates strong self-reported symptoms, but while many features are found on neuropsychological testing, a smaller number reach the 50% level:

Self-Reported:

- General memory deficit (10/10)
- Deficit in Concentration (5/10)
- Aggression (5/10)
- Low Libido (6/10)

Neuropsychological testing:

- Processing Speed Deficit (5/10)
- Vocabulary and Word Finding Deficit, and Verbal Learning Deficit (5/10)
- The remaining features are present as may be seen in the

table, but less prominently on testing. This group might be thought of as more subjectively impaired.

Group G1B

Subgroup G1B however demonstrates substantial impairment both subjectively and objectively. In addition to the general G1 symptoms above, G1B also demonstrates the following self-reports and testing results in 50% or more of the patients. This group demonstrates substantial proportions, which are partly responsible for enhancing the proportions for the group as a whole.

Self Reported:

- General memory deficit (5/6)
- Loss of "Mental Powers" (3/6)
- Deficit in Concentration (5/6)
- Aggression (5/6)
- Electrical Phobia (3/6)
- Low Libido (6/6)
- Social Isolation (4/6)
- Low Mood/Depression (3/6)

Neuropsychological testing:

- Auditory Memory Deficit (6/6)
- Processing Speed Deficit (5/6)
- Vocabulary and Word Finding Deficit, and Verbal Learning Deficit (4/6)
- Verbal Fluency (5/6)
- Visual Memory Deficit (3/6)

Table 1 Numbers in each group after Cluster Sorting

Group clusters	G1 (n = 16)	G1A (n = 10)	G1B (n = 6)	G2 (n = 10)	G2A (n = 5)	G2B (n = 5)	G3 (n = 1)
Self report							
Memory generally	15	10	5	2	1	1	1
Concentration deficit	12	7	5	3	2	1	1
Loss of "mental power"	11	8	3	1	1		1
Aggression	10	5	5	4	2	2	1
Electrical phobia	9	6	3	5		5	1
Low libido	7	1	6	1		1	
Social isolation	7	3	4	2		2	
Vocabulary and word finding	5	5		2	1	1	1
Low mood	3		3	2		2	1
Learning dysfunction	1	1		1	1		
Anxiety	1	1		3	1	2	
Marital stress	1	1		2		2	
Neurpsych testing							
Auditory memory	10	4	6	6	4	2	
Processing speed	10	5	5	1		1	1
Vocabulary/word-finding/verbal learning	9	5	4	5	5		1
Verbal fluency deficit	7	2	5	4	2	2	1
Visual memory deficit	6	3	3	3	2	1	1
Concentration loss	6	3	3	5	5		1
Executive and cognitive proc loss	5	3	2	4	2	2	
Loss of attention span	5	1	4	4	4		1
Anxiety	5	3	2				
General memory deficit	4	1	3	1	1		
Visuo-spatial deficit	4		4	6	4	2	
Verbal intelligence quotient (IQ) loss	4	2	2	1	1		1
IQ decrease	1		1	1	1		

Shading represents those symptoms at 50% frequency or more in each group.

Concentration Ability Loss (3/6)
 Attention Span Loss (4/6)
 General memory Deficit (3/6)
 Visuo-Spatial Defect (4/6)

G2 as a whole (G2A – 5; G2B-5)

Using the prevalence figures to define G2 as a whole, the same symptoms are self-reported, but only the presence of an electrical phobia reaches a 50% prevalence. G2, while injured, can be considered a lesser injured group.

Nonetheless on testing, similar findings at the 50% level emerge, and these are:

Auditory memory deficit (6/10)
 Visuo-spatial deficit (6/10)
 Vocabulary and Word Finding Deficit, and Verbal Learning Deficit (5/10)
 Loss of Concentration Ability (5/10)

G2A findings

The items which reach the 50% level in G2A are:

Loss of concentration ability (5/5)
 Loss of Attention Span (4/5)
 Visuo-spatial deficit (4/5)

and these are on objective testing grounds.

G2B findings

The self-reported occurrence of electrical phobia (5/5) is the main finding in G2B.

Nonetheless the expected findings in other groups are also represented, just in fewer quantities.

While Cluster Analysis can be used to identify subgroups of differing severity and differing co-existing findings within a cohort, this aspect is not pursued further in the present analysis other than to note the existence of subgroups. Each of the subgroups demonstrate symptomatology of a similar kind, albeit in differing degrees.

The next step is to take the common elements of PELIS demonstrated by the analysis and construct a set of criteria suitable for inclusion in the DSM in order to place the PELIS diagnosis on a firm footing. The aim in constructing a set of DSM criteria is to concentrate on the psychological and psychiatric aspects of the condition. In constructing the diagnostic formulation which appears below, physical and contextual matters are included, however, the focus for the DSM is psychological. It is asserted that all individuals in the analysis presented satisfy the physical and contextual criteria, and the psychological aspects are the focus of the proposed criteria.

Given the analysis, it will be seen that criteria for the psychological and psychiatric definition must accommodate the following features, in varying broad subject areas:

A. Frequent Features

Memory and Learning Group

Subjective memory loss
 Auditory memory loss
 Verbal memory loss

Vocabulary and Word Finding Deficit, and Verbal Learning Deficit

Executive Function and Cognitive Processing Group

Loss of Executive Ability and cognitive power
 Loss of Executive Processing Speed
 Loss of Concentration Ability

Loss of attention span

Psychological and Behavioural Features

Depressive features, including low mood, aggression, and social isolation.

Electrical Phobia

B. Moderately frequent features

Memory and Learning Group

Visual memory deficit

Executive Function Group

Loss of Verbal Fluency and Word Finding Ability

Loss of Attention Abilities

Visuo-spatial Deficit

Psychological Features

Loss of libido, a common symptom of which is relationship breakdown.

These are now placed in a framework to allow diagnosis of PELIS, and the following discussion indicates a proposal for their integration.

We thus advance the diagnostic criteria shown in **Table 2**, invite reflection on it, and invite its use in assessing the victims of ELI.

The Proposed DSM Criteria

Each section of the criteria and the reasons for their inclusion are now examined and discussed.

Context

It is most important that the injury is diagnosed only in context. There has been an indication that some of the features of the PELIS are held in common with other injuries. In particular, a similarity with a closed head injury has been raised (Primeau et al., 1995b; van Zomeren et al., 1998). While such an injury may share some commonality with PELIS, the proposed criteria are intended to refer specifically to ELI consequences. Criteria for similar syndromes, like closed head injury, might well be proposed by others. The contextual items include a technical appraisal consistent with ELI, and physical findings consistent with ELI.

Electrical Context

The assessment of ELI is somewhat specialised. Certain electrical knowledge is required, and the use of an electrical standard (IEC, 2007) may be helpful. The confirmation of electrical parameters may necessitate the engagement of/consultation with an electrical scientist, preferably one with expertise in ELI. Similarly, the assessment of neuropsychological state ought to involve formal neuropsychological testing. Self-reported symptoms are important, and psychiatric diagnosis is often made on the basis of subjective self-report. Nonetheless, there should be some attempt to objectify especially the executive loss in individual patients, and neuropsychological testing is desirable in this context. As a caveat however, Andrews (2006), has noted that there remains a degree of interpretive variability in this testing. Thus it is recommended that a tester familiar with the injury should be considered.

Timing

A delay in the onset of psychiatric symptoms has been reported many times and is accepted as common in ELI (Andrews and Reisner, 2017). Some writers have postulated many years of delay. However, it seems reasonable to place a limit on the delay which is acceptable. Given the progress of the deterioration

Table 2 Proposed American Psychiatric Association's Diagnostic and Statistical Manual (DSM) Diagnostic criteria for the diagnosis of the psychiatric features of the post electrical or lightning injury syndrome (PELIS)

Diagnostic Criteria for 999.9 Post Electric or Lightning Injury Syndrome (PELIS)
<p>These criteria, when met, establish the diagnosis of the psychiatric syndrome occurring in consequence of an electrical or lightning injury (ELI). The patient may need assessment and treatment for the physical consequences of the injury as a separate process.</p> <p>The criteria required to meet a diagnosis of PELIS must be met within a context of an electric or lightning injury, preferably established by a physician or electrical scientist familiar with the physical assessment of electric and lightning shock mechanisms, and must be met in the absence of confounding conditions.</p> <p>Nonetheless it may be considered that a pre-existing condition may have been exacerbated by the electrical or lightning shock.</p> <p>A. CONTEXT The psychiatric symptoms must:</p> <ol style="list-style-type: none"> i. be present in the context of an electrical or lightning injury which has been formally assessed, and preferably confirmed by a physician or electrical scientist familiar with the assessment of electrical or lightning injuries; <p>AND</p> <ol style="list-style-type: none"> ii. date from the injury, which is taken to include the appearance and/or development of the symptoms within a period up to 24 months following the injury; <p>AND</p> <ol style="list-style-type: none"> iii. include a physical aspect defined by <ol style="list-style-type: none"> 1. any two of <ol style="list-style-type: none"> a. weakness of musculature in the line of the current b. easy physical fatiguing of the musculature in the line of the current leading to loss of full functional task performance c. Lack of physical stamina <p>AND</p> <ol style="list-style-type: none"> 2. any one of the following <ol style="list-style-type: none"> a. ocular abnormalities b. hearing abnormalities, including ruptured tympanic membrane c. tinnitus d. balance disorder e. Burns at either or both of entry and exit sites, or in the case of lightning injury, burns in one of the six classic lightning patterns f. Peripheral Nerve Dysfunction in the line of the current, including tremor g. Sensory abnormality in the line of the current, which may include pain, paraesthesiae, and/or a Complex Regional Pain Syndromes (CRPS) h. Cardiac Abnormalities, transient or long-term, including QTc prolongation. i. Myoglobinuria at the time of the injury <p>B. EXCLUSIONS The symptoms must occur in the absence of</p> <ol style="list-style-type: none"> a. Any pre-existing medical illness, or organic cerebral change save that documented as being in consequence of the injury itself, which produces equivalent psychiatric symptoms in its normal course despite the presence of the contextual features b. Any associated traumatic syndrome which produces equivalent psychiatric symptoms in its normal course despite the presence of the contextual features until such traumatic injury is fully resolved c. Any consequence of the intake of substances, prescribed or otherwise, which produces psychiatric symptoms, until the consequences of such intake have been fully resolved d. Any hypoxic insult in consequence of the injury which produces the psychiatric symptoms despite the presence of the contextual features, and in this case the diagnosis of consequences of hypoxic damage secondary to the injury in question may be entertained as an alternate e. Any neurodevelopmental or neurobehavioural condition, such as ADHD, Autistic Spectrum Disorder, or the like, though the clinician may wish to consider that the PELIS coexists with such a condition or has exacerbated the condition. <p>C. NEUROPSYCHIATRIC ASPECTS The criteria for diagnosis of the PELIS must include a finding in each of three groups:</p> <ol style="list-style-type: none"> 1. Executive Elements Either (On formal testing) <ul style="list-style-type: none"> Loss of Executive Processing Speed, or Loss of Executive Ability (such as ability to follow plans, recipes, diary maintenance), or Loss of Concentration Ability, or Attention Span, or Loss of Verbal or Auditory Learning Ability Or (on self-report) any two of <ul style="list-style-type: none"> Loss of daily executive work powers (such as ability to follow plans, recipes, diary maintenance, financial record keeping, prepare work documents such as quotes, or similar) Loss of attention span Loss of Concentration ability Mental slowing 2. Memory Elements Either <ul style="list-style-type: none"> A testing finding of either auditory or verbal memory loss, or Or <ul style="list-style-type: none"> A subjective report of any two of general memory difficulty, vocabulary and word finding difficulty, and verbal fluency 3. Miscellaneous Group (at least one of) <ul style="list-style-type: none"> Depression, including low mood, aggression, anhedonia Loss of Libido including relationship disturbance Social Isolation and reclusiveness Phobia for electrical apparatus Mental fatigue and sleep abnormality Loss of mental resilience <p>Supportive Elements Supportive elements may substitute for one category only above</p> <p>Any of</p> <ol style="list-style-type: none"> a. Formally diagnosed PTSD b. Formally diagnosed Adjustment Disorder c. Hippocampal loss of volume on neuroimaging

above giving a deterioration for up to 2 years, it seems reasonable to limit delay to 24 months.

Physical Context

The psychological injury can only be diagnosed in concert with physical findings. For EI, the most consistent findings are weakness of musculature in the line of current passage, with easy fatiguing of the muscles and loss of stamina of those muscles. Sensory abnormalities are often prominent, with pain, numbness, and/or paraesthesia in the line of current. A representative number of these is required.

Other physical findings are seen variably, and thus can be included in addition to the items required in the preceding paragraph. These include sensory organ abnormalities in eyes (cataract, accommodation difficulties, visual field defects, or extraocular movement disorders), ears (hearing loss, tinnitus, balance abnormality, with ruptured tympanic membrane being especially common in lightning injury), or dysfunction in various neural systems (ALS, MND, or similar). Burns may be present, though the absence of burns does not dissuade one from an ELI diagnosis. Cardiac abnormalities also may or may not be present. QTc abnormalities are easily overlooked, and viewing an acute ECG is valuable.

Exclusions

Excluding confounding pathologies is important, as similarly seen in other DSM criteria. The exclusions fall into typical categories, viz., pre-existing confounding medical illness which could produce similar symptoms; an associated traumatic condition, at least until the effects of that trauma have resolved; substance intake; hypoxic insult, though we note the possibility of hypoxic insult secondary to ELI; and neurodevelopmental or neurobehavioural disorders.

Nonetheless, there is an added caution that, while a pre-existing condition may exclude a diagnosis of PELIS, it is possible for the injury to exacerbate the existing condition where it coexists, especially in the case of repeated ELI.

Neuropsychiatric aspects

The aim of this proposal is to formalise the neuropsychiatric aspects of the injury. The formalisation must accommodate the findings itemised above.

The almost universal findings in PELIS are executive deficits of particular kinds (Andrews, 2006; Andrews and Reisner, 2017), memory disturbance with an emphasis on auditory and verbal memory, and degrees of several miscellaneous features, including a social withdrawal, phobic responses, mental fatigue and loss of resilience.

Testing, as above, has indicated refinement of these. The refinements include memory dysfunction, such as (auditory and verbal), learning dysfunction (especially auditory), visuo-spatial deficit, word finding difficulty, and executive function abnormality, often reported to include loss of organisational ability, slowed thinking, clouded thinking, loss of deductive facility, executive speed deficit, and loss of planning and management ability. In addition, history given to the writers can also include subjective personality change and loss of relationship interaction ability leading to substantial inter-partner dysfunction.

The key findings would appear to be memory elements and executive elements. The proposed criteria should allow the diagnosis based on the presence of each of these, and combinations are chosen to allow inter-variability between subjects which

together allow the diagnosis to be satisfied.

While individual features can be found in other disorders, for example closed head injury, it is emphasised that PELIS must be diagnosed in the context of an electrical event. The criteria take on a diagnostic formulation for PELIS only in context of an electrical or lightning incident.

Findings in each area have been suggested, and these are discussed below with the final criteria summarised in **Table 2**. It is suggested that each of the three element groups should be satisfied. In general, in each area, one objective testing finding will satisfy, or alternatively two self-reported symptoms.

Executive elements

Executive function is prominently featured. Formal testing findings have been specified in their own right, or more than one subjective self-reported symptom is allowed:

Either (Loss found to be significant on formal testing)

- Loss of Executive Processing Speed, or
- Loss of Executive Ability (such as ability to follow plans, recipes, diary maintenance), or
- Loss of Concentration Ability, or Attention Span, or
- Loss of Verbal or Auditory Learning Ability

Or (on self-report) any two of

- Loss of daily executive work powers (such as ability to follow plans, recipes, diary maintenance, financial record keeping, prepare work documents such as quotes, or similar)
- Loss of attention span
- Loss of Concentration ability
- Mental slowing

Memory elements

The common self-report is of subjective memory loss, and this is refined at testing to be auditory memory loss, and verbal memory loss, with loss being deviation below premorbid projections, and/or inconsistent with indices of other executive functions. Vocabulary finding is included in this group.

To allow for similar inter-subject variability, the following are proposed:

Either

- A test finding of either auditory or verbal memory loss

Or

- A subjective report of any two of general memory difficulty, vocabulary and word finding difficulty, and verbal fluency

Miscellaneous group

Miscellaneous items are also present and allowing these as adjuncts is suggested.

- Depression, including low mood, aggression, anhedonia
- Loss of Libido including relationship disturbance
- Social Isolation and reclusiveness
- Phobia for electrical apparatus

Table 2 shows the developed criteria incorporating the above. There is also a supportive segment allowing the addition of presently diagnosed syndromes, and neuroimaging findings which the authors have referred to elsewhere (Andrews and Reisner, 2017), but which were not tested in the cluster analysis shown above.

Treatment Options

This paper provides a tool to enhance treatment of, and research

into, ELI. Firm diagnosis on established criteria are fundamental to therapy, and also to ensure the selection of correct study groups in a research study. Treatment may be evaluated with appropriate study group selection.

Treatment strategies should address multiple aspects of the condition. These aspects are delineated by a diagnostic structure as proposed.

Important aspects are used currently, and avenues of treatment which may be fruitful have been referred to in a previous article (Andrews and Reisner, 2017).

Given the findings of hippocampal cell loss/atrophy in depression (Sheline et al., 1996; Vogel, 2000), PTSD (Bremner, 2006) and as a primary phenomenon in electrical injury (Kurtulus, 2008), an antidepressant is considered an important starting point (Andrews and Reisner, 2017). Bremner (*at p449*) notes in relation to PTSD: “Both hippocampal atrophy and hippocampal-based memory deficits reversed with treatment with the selective serotonin reuptake inhibitor (SSRI) paroxetine, which has been shown to promote neurogenesis (the growth of neurons) in the hippocampus in preclinical studies.”

It has also been noted that treatments for depression, including antidepressants, “...have been shown to promote new cellular growth in the hippocampus of animals” (Duman and Vaidya, 1998; Reisner, 2003).

Further existing treatment has been commenced on a more empirical basis. This includes the use of analgesics for neuritic pain, such as pregabalin or gabapentin.

Coupled with these pharmacological treatments, non-pharmacological strategies are important. Following comprehensive neuropsychological testing, neuropsychological counselling and intervention are strongly advised. Psychiatric care will also be of benefit.

This article however is intended to guide future treatment options by facilitating clinical research. The previous paper suggests that antagonists for glutamate, for oxidative free radicals, and for cortisol, may be of benefit (Andrews and Reisner, 2017). Trials of such medication are in the planning stage and it is hoped will yield useful treatments.

However in order to conduct well-ordered and cogent trials, firm diagnoses are required. The criteria proposed in this paper will place such trials on a firm basis. A clear diagnosis will facilitate clinical research and may lead to better treatment for those who suffer from lightning and electrical injury.

Conclusion

The writers have proposed a definition of the PELIS in a manner suitable for a DSM diagnosis. The definition takes into account the context of the injury and the injury features require appraisal within that context. The definition requires accompanying evidence of the injury in physical terms, and suggests exclusory conditions precluding the diagnosis. Nonetheless, it is pointed out that the PELIS may complicate pre-existing conditions.

Psychological elements are prescribed, and are represented in a mix of self-reported symptoms, and also the results of formal neuropsychological testing.

The criteria are proposed and comment and experience is invited. They are proposed in order to provide a basis for systematic and just assessment of victims, as well as an aid for systematic research and on which to base treatment. They are proposed to take into account the full range of findings in the syndrome, where hitherto these have only been partially used.

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Open peer review reports:

Reviewer 1: Marvin Antonio, Escuela Superior de Medicina IPN, Mexico.

Comments to authors: The manuscript is a good review and contents an attractive proposal for DSM.

Reviewer 2: Ubaldo Armato, University of Verona Medical School, Italy.

Comments to authors: It is an important though currently little considered topic: proper therapy will lead to neural regeneration particularly in the hippocampus. It is a clear and well constructed review on a little considered topic presenting suggestions about more stringent diagnostic criteria leading to better therapeutic interventions.

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