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COMMENTARY
A call for neurovascular monitoring in an era of longer missions and broader spaceflight participation

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Abstract
Spaceflight-Associated Neuro-ocular Syndrome (SANS) has emerged as a critical neuro-ophthalmic risk for human space exploration, particularly as mission duration increases and access to space expands. Current spaceflight ocular surveillance and research protocols have prioritized structural imaging and selected neuroimaging/physiological assessments. However, accumulating evidence suggests that SANS is not confined to the posterior pole as a purely structural optic nerve head phenomenon but may also involve vascular and hemodynamic alterations. At the same time, structural changes at the optic nerve head may not fully capture the functional integrity of the afferent visual pathway. We therefore propose to define a more targeted extension of current SANS surveillance protocols incorporating ultra-widefield swept-source optical coherence tomography angiography (UWF-SS-OCTA), visual evoked potentials (VEPs) and pattern electroretinogram (ERG) into standardized pre-flight, in-flight (when feasible), and post-flight assessments. Beyond its relevance to astronaut health, this topic may also be of translational interest to the broader scientific and clinical community.

Key words
- electroretinography
- retina
- space flight
- astronauts
- ophthalmic nerve

Spaceflight-Associated Neuro-ocular Syndrome (SANS) has emerged as a critical neuro-ophthalmic risk for human space exploration, particularly as mission duration increases and access to space expands [1].

SANS refers to a constellation of findings observed during and after long-duration spaceflight, including optic disc edema, posterior globe flattening, choroidal and/or chorioretinal folds, and hyperopic refractive shifts, with potential implications for visual performance and operational safety [1].

As national and commercial programs plan longer missions, greater cumulative exposure, and more diverse participant profiles, the need for sensitive, mechanism-informed ocular monitoring becomes increasingly urgent [2].

With the expansion of access to space, addressing the current lack of sex-specific evidence in SANS will become increasingly important, as will ensuring that future monitoring protocols explicitly incorporate sex-disaggregated analyses where feasible.

Current spaceflight ocular surveillance and research protocols have prioritized structural imaging and selected neuroimaging/physiological assessments [3]. A major step forward is the integrated NASA research framework, including the "Complement of Integrated Protocols for Human Exploration Research" (CIPHER) and its ocular study, "Investigating Structure and Function of the Eye" (iSAFE), which incorporates optical coherence tomography (OCT), standard OCT angiography (OCTA), visual field testing, electroretinography (ERG), ocular biometry, and intraocular pressure measurements (https://www.nasa.gov/reference/cipher/).

Nevertheless, important gaps remain in the vascular and functional neuro-ophthalmic domains, which may be particularly relevant to early detection, individual risk stratification, evaluation of countermeasures, and identification of subclinical sequelae not captured by standard assessments.

A similar principle has emerged in other ophthalmic settings, including drug-related retinal toxicity, where

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combining vascular imaging and electrophysiology has helped reveal persistent abnormalities not fully explained by structural findings alone [4, 5].

Beyond its relevance to astronaut health, this topic may also be of translational interest to the broader scientific and clinical community. Human research in space has repeatedly generated insights relevant to terrestrial medicine, including cardiovascular, neurovestibular, pulmonary, and immune physiology [6, 7]. In the specific case of SANS, spaceflight provides a unique human model of chronic fluid shift, altered venous and cerebrospinal fluid dynamics, and neuro-ocular adaptation under conditions that cannot be fully reproduced on Earth. In this sense, efforts to refine neurovascular monitoring in SANS may also contribute to the study of terrestrial disorders characterized by optic disc edema, disturbed cerebrospinal fluid dynamics, or neuro-ophthalmic involvement [8].

Therefore, our proposal is to define a more targeted extension of current SANS surveillance protocols to better capture neurovascular and functional changes across pre-flight, in-flight, and post-flight assessments. *Table 1* summarizes the main existing surveillance elements, along with the proposed additions, their rationale, and expected benefits.

First, accumulating evidence suggests that SANS is not confined to the posterior pole as a purely structural optic nerve head phenomenon but may also involve vascular and hemodynamic alterations associated with chronic headward fluid shifts. At present, these vascular changes should be regarded as plausible contributors to SANS pathophysiology rather than established primary drivers, and may, in some cases, also represent downstream manifestations of broader fluid-shift, venous outflow, and CSF-related disturbances [1, 3, 8]. Retinal vascular patterning analyses in astronauts have reported post-flight reductions in vascular density, with the most pronounced changes occurring in eyes showing clinical SANS features [9]. These observations support the rationale for vascular biomarkers that complement structural OCT. We therefore propose that the scientific community consider incorporating ultra-widefield swept-source OCTA (UWF-SS-OCTA) into standardized pre-flight, in-flight (when feasible), and post-flight assessments.

At present, the most immediate role of UWF-SS-OCTA would likely be in standardized pre- and post-flight surveillance, while in-flight implementation should be considered a feasible but forward-looking objective. This is conceptually consistent with the progressive adoption of portable ocular imaging in spaceflight, although dedicated validation would still be required to address portability, crew time, acquisition quality in microgravity, equipment handling, protocol standardization, and training requirements. Similar operational considerations would also apply to the broader integration of electrophysiological testing.

Compared with conventional spectral-domain OCTA, UWF-SS-OCTA can better visualize and quantify peripheral retinal perfusion and may provide a more robust investigation of the choriocapillaris and deeper choroidal circulation, tissues that are potentially sensitive to venous congestion, altered translaminar pressure gradients, and autoregulatory stress during microgravity exposure [10, 11]. These measurements could provide quantitative biomarkers for identifying subclinical vascular abnormalities, as well as for assessing the evolution or recovery of vascular changes associated with SANS.

Table 1
Current surveillance elements and proposed neurovascular-functional additions for Spaceflight-Associated Neuro-ocular Syndrome (SANS) monitoring

Spaceflight surveillance protocol element	Rationale	Expected benefit
Current protocol		
Optical coherence tomography (OCT)	Detects the main structural ocular changes associated with SANS (optic disc edema, chorioretinal folds)	Diagnosis and longitudinal structural assessment across the peri-mission timeline
Spectral-domain OCT-angiography (SD-OCTA)	Provides information on retinal microvasculature	Assessment of central retinal vascular changes
Visual field testing	Evaluates the functional visual consequences of neuro-ophthalmic changes	Detection of visual dysfunction relevant to mission performance and follow-up
Electroretinography (ERG)	Assesses retinal cellular function	Functional evaluation of retinal involvement
Ocular biometry	Helps document globe flattening and hyperopic shifts	Additional characterization of ocular structural remodeling
Intraocular pressure measurements	Provides a basic physiological parameter relevant to ocular status	Supportive physiological monitoring
Proposed additions		
Ultra-widefield swept-source OCTA (UWF-SS-OCTA)	Captures and quantifies retinal and choroidal vascular alterations over a wider and deeper field than standard OCTA	Improved microvascular characterization of SANS-related changes and possible subclinical sequelae
Visual evoked potentials (VEPs)	Provide an objective measure of afferent visual pathway function	Earlier identification of subclinical functional abnormalities and detection of dysfunction not fully explained by structural imaging or retinal functional assessment alone

Second, SANS is fundamentally a neuro-ophthalmic condition: structural changes at the optic nerve head may not fully capture the functional integrity of the afferent visual pathway [12]. Analogously, in other retinal and optic nerve conditions, structural recovery does not necessarily imply full functional normalization, underscoring the value of objective electrophysiological endpoints. Visual evoked potentials (VEPs) and pattern ERG provide an objective, quantitative measure of signal transmission from the retina/optic nerve to the visual cortex and may detect very early functional abnormalities in papilledema due to intracranial hypertension [13]. VEP acquisition has already been demonstrated in astronauts during weightlessness, with identifiable evoked components recorded in-flight and compared with pre- and post-flight sessions [14].

The broader rationale for integrating VEPs into SANS surveillance also draws on evidence from related neuro-ophthalmic conditions, where electrophysiology can reveal functional abnormalities not fully captured by structural imaging; in this sense, our recommendation remains a plausible, albeit prospective, extension of the protocol.

Integrating VEPs into current protocols, ideally with strict refractive correction, and using spatio-temporal stimuli that favor both magnocellular and parvocellular contributions could complement OCT/OCTA by detecting subclinical conduction changes, distinguishing optical blur from neuroaxonal dysfunction, and providing meaningful functional outcomes for countermeasure trials.

In summary, we urge the scientific community to view SANS surveillance as an evolving, multidisciplinary monitoring challenge and to help inform the assessment frameworks adopted by space agencies in an era of planned long-duration missions. The addition of UWF-SS-OCTA (to better characterize retinal and choroidal microvasculature across a wider field) and VEPs (to quantify visual pathway function) to existing protocols could provide a more complete neurovascular and functional characterization of SANS, thereby strengthening early detection, refining pathophysiological understanding, and supporting the development and evaluation of countermeasures across the full perimission timeline.

Conflict of interest statement

The Authors declare no conflict of interest.

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