Short communication

Critical flicker fusion frequency measurement through a chamber porthole

Jochen D Schipke[1], Thomas Muth[2], Anne-Kathrin Brebeck[3], Sven Dreyer[4]

[1] *Research Group Experimental Surgery, University Hospital Düsseldorf, Germany*
[2] *Institute of Occupational, Social, Environmental Medicine, Faculty of Medicine, Heinrich-Heine-University Düsseldorf, Düsseldorf, Germany*
[3] *Artemis Augenkliniken, Frankfurt am Main, Germany*
[4] *Hyperbaric Oxygen Therapy, University Hospital Düsseldorf, Düsseldorf, Germany*

Corresponding author: *Professor Jochen Schipke, Research Group Experimental Surgery, University Hospital Düsseldorf, Germany*
ORCID: *0000-0002-1747-5657*
j.schipke@gmx.org

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Abstract

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The critical flicker fusion frequency (cFFF) is a non-invasive measure of central nervous system function and cortical arousal, increasingly used in diving and hyperbaric medicine to assess the effects of breathing gases under pressure. This feasibility study aimed to evaluate whether cFFF can be reliably measured through the porthole of a hyperbaric chamber. Forty-five experienced male divers underwent cFFF testing at various pressures (101.3 kPa outside chamber, then 101.3, 608, 132, 101.3 kPa inside [1.0 bar outside then 1.0, 6.0, 1.3, 1.0 bar inside]) using a manually operated LED flicker-device while standing at a fixed distance from the chamber window. Results showed that cFFF values were higher inside the chamber at 101.3 kPa (1.0 bar) compared to outside (45.6 Hz vs. 40.2 Hz), decreased under hyperbaric conditions (608 kPa [6 bar], 43.5 Hz), and declined further during decompression (132 kPa [1.3 bar], 42.1 Hz; 101.3 kPa [1.0 bar], 43.5 Hz). These findings support previous observations of gas-induced central nervous system effects and highlight the sensitivity of cFFF to pressure-related neural changes. The successful external measurement protocol addresses challenges associated with observer narcosis and movement artifacts in underwater settings. While limited by the homogenous participant group and lack of confirmatory measures, this approach may still be a valuable tool for future research into the temporal dynamics of gas narcosis and cortical excitation.

Introduction

At or above the critical flicker fusion frequency (cFFF), a flickering light stimulus is perceived as steady by the observer. As such, cFFF serves as a measure of the brain's temporal resolution and has proven valuable for assessing cortical arousal and central nervous system (CNS) function – a property recognised over 30 years ago.[1] More recently, particularly in diving contexts, this non-invasive and easy-to-use technique has been employed to evaluate alertness and cognitive performance in divers.[2] CFFF has also been used more broadly to assess CNS function and arousal.[3,4]

In diving and hyperbaric medicine, cFFF has helped investigate the neurological effects of breathing gases under pressure, though findings remain inconsistent. For example, cFFF decreased under 142 kPa (1.4 bar) oxygen but recovered at 284 kPa (2.8 bar), indicating dose-dependent neural effects,[5] whereas 100% O_2 at 101.3 kPa and 284 kPa (1 and 2.8 bar) also reduced cFFF – but not at 608 kPa (6 bar).[6] Nitrox breathing produced mixed results: transient cFFF increases followed by decline,[7] enhanced post-dive alertness,[8] or a protective effect versus air.[9] Scuba dives to 33 m showed initial cFFF elevation, followed by lasting decreases post-dive.[10] Rebreather dives with air, trimix, or heliox revealed mild increases without long-term effects,[2,11] whereas trimix bounce dives to 100 m showed no change.[12]

One possible explanation for the contradictory results is likely described by Freiberger and colleagues.[13] These authors indicate that CO_2 plays a critical role under hyperbaric conditions, interacting with N_2 and exercise to cause narcosis, which may be worsened by O_2, while at the same time, sea level O_2 partially rescued motor and memory reaction time impaired by CO_2.

The heterogeneous outcomes highlight that the effects of nitrogen, oxygen, CO_2 and inert gases – individually or in combination – on CNS function under pressure remain only partially understood.

Given the need for further investigation, this study aimed to evaluate whether cFFF measurements taken externally through the porthole of a hyperbaric chamber are feasible and yield results consistent with previous findings.

Methods

The study protocol was reviewed and approved by the Ethics Committee of the Medical Faculty, Heinrich Heine University Düsseldorf, in accordance with the Declaration of Helsinki,[14] Approval No. 2023-2493.

Forty-five experienced male divers from five professional fire departments and a diving club participated in the study (mean age 34.6 [standard deviation (SD) 6.6] years; height 182 [SD 7] cm; weight 84.6 SD [6.6] kg; body mass index 26.4 [SD 2.1] $kg \cdot m^{-2}$). All subjects completed a training dive at 608 kPa (6 bar) in a hyperbaric chamber at the hyperbaric oxygen therapy facility of the University Hospital Düsseldorf (Germany).

A manually operated flicker light (Scaleo, Esslingen, Germany; single LED, 8000 K) was used for cFFF testing. A consistent distance of 1.5 m between the device and the participant was maintained by the same experienced examiner throughout all measurements.

STATISTICAL ANALYSIS

A repeated measures ANOVA was conducted (ChatGPT), followed by a Bonferroni post-hoc test. The measurements differed significantly from each other at $P < 0.05$.

Approximately a decade ago, the American Statistical Association recommended caution in the use and interpretation of *P*-values and statistical significance.[15] Accordingly, for our simple five-step protocol, we evaluated differences in cFFF values using Cohen's d.[16]

PROTOCOL

Critical flicker fusion frequency was first measured outside a 12-person hyperbaric chamber (Haux, Life Support, Karlsbad, Germany). Subsequently, and following the same participant order, cFFF was measured inside the chamber through the door's porthole at ambient pressures of 101.3, 608, 132, and again at 101.3 kPa (1.0, 6.0, 1.3, 1.0 bar). For each measurement, the flicker frequency was continuously increased from a low to a high value until the participant gave a predefined 'OK' hand signal, indicating their individual cFFF threshold had been reached.

Since the examiner remained the same throughout and the participants were thoroughly informed in advance about the procedure for determining the fusion frequency, we limited the assessment to a single measurement, although performing three measurements would likely have yielded even more precise cFFF values.

Participants were instructed to stand still near the porthole and maintain steady gaze fixation without moving their eyes during the measurement. A fixed distance of 1.5 m between the observer and the participant was maintained at all five time points.

Results

Normobaric (101.3 kPa) cFFF measured inside the chamber was significantly higher than the values obtained outside the chamber (mean 45.6 [SD 4.7] Hz vs. 40.2 [SD 4.3] Hz), with a large optically related effect size indicated by Cohen's $|d| = 1.2$.

Following compression to 608 kPa (6 bar), cFFF decreased compared to the initial 101.3 kPa (1 bar) measurement inside the chamber (mean 43.5 [SD 4.6] Hz vs. 45.6 [SD 4.7] Hz; $P < 0.05$; $|d| = 0.45$, medium effect). A decrease in cFFF was observed from 608 kPa (6 bar) to the 132 kPa (1.3 bar) reading during decompression (43.5 [SD 4.6] Hz vs. 42.1 [SD 4.2] Hz; $P < 0.05$; $|d| = 0.32$, small effect). The normobaric (101.3 kPa) cFFF at the end of the session (following decompression) was lower compared to the beginning (45.6 [SD 4.7] Hz vs. 42.6 [SD 4.6] Hz; $P < 0.05$; $|d| = 0.65$, medium effect). The relative decreases beginning from the normobaric cFFF-value were equal to 4.6%, 7,7%, and 6.6%, respectively.

Discussion

This feasibility study aimed to determine whether the cFFF of individuals exposed to varying pressures inside a hyperbaric chamber can be reliably assessed from outside the chamber through the porthole in the chamber door. The results indicate that this experimental setup is both feasible and capable of yielding plausible data.

The observed decrease in cFFF under hyperbaric conditions (608 kPa [6 bar]) aligns with previous reports suggesting that elevated partial pressures of nitrogen can induce narcosis[9,17] and can transiently impair cortical processing.[5,6]

The modest yet consistent decline in cFFF during decompression in this study may indicate a lingering effect of gas narcosis, fatigue, or altered neural excitability. The final normobaric value being lower than the pre-dive baseline suggests that even short exposures to hyperbaric conditions can produce temporary alterations in central nervous system function detectable by cFFF.[10,18]

Importantly, the effect sizes observed in this study ranging from small to large, highlight the sensitivity of cFFF to changes in ambient pressure and support its use as a non-invasive, easy-to-use, real-time marker of cortical arousal during and after hyperbaric exposures.

When conducting studies at elevated pressures, observers themselves are also at risk of experiencing the effects of nitrogen narcosis. This poses a significant challenge for cFFF-based assessments of CNS function under different breathing gas mixtures, as reliable measurements are difficult to obtain, if the observer is impaired by nitrogen narcosis. Therefore, it is desirable for the observer to be able to conduct these measurements from outside the chamber.

The cFFF is primarily determined by the spatial distribution of photoreceptors (cones and rods) on the retina. When a light stimulus flickers, the flicker is perceived more intensely if it is projected directly onto the fovea than when viewed peripherally. Consequently, the highest cFFF values are observed when the stimulus strikes the fovea.[19] Therefore, it was essential to maintain a consistent distance between the light source and the participant's eyes as well as a constant visual angle throughout the protocol.

This consideration is particularly important, as deviations in the relative positioning of the light source and the eyes can influence the outcome. For example, in underwater diving research, measurements are often performed both at the surface and at depth, where maintaining fixed positions is inherently more difficult.

Additionally, any movement of the observer or the light source can affect cFFF values. A particularly notable source of error is eye movement, especially saccades, which can significantly distort results. During saccadic eye movements, humans have been shown to perceive flicker frequencies as high as 2,000 Hz.[20]

LIMITATIONS

This study's focus on experienced male divers may limit generalisability, but this cohort was deliberately chosen to reduce variability from confounding factors such as experience, age, and sex.

Another limitation is the interpretation that reduced cFFF reflects inert gas narcosis. While this is plausible, confirmatory measures like EEG or cognitive testing were beyond the scope of this feasibility study, which aimed primarily to assess protocol viability.

Lastly, cFFF values measured in the hyperbaric chamber were 13% higher than outside, potentially affecting comparability with other studies. However, normalising baseline values to 100% a method supported by previous research, can mitigate this issue.[6,10]

Conclusions

This feasibility study demonstrated that cFFF measurements can be successfully conducted from outside a hyperbaric chamber and can yield valid and interpretable results. The observed cFFF reduction is consistent with the effects of nitrogen narcosis under elevated ambient pressure, which appear to persist beyond the period of exposure. At the same time, the increase in cFFF due to refraction through the chamber window highlights a methodological issue in field studies where flickering light passes through different media such as water, glass, and air, potentially altering measurement outcomes.

The novel approach to cFFF measurement conducted externally through the chamber porthole may support future investigations into the effects of breathing gases under elevated pressure by eliminating the risk of observer impairment. For example, it is conceivable that a transient euphoric phase, possibly related to elevated oxygen partial pressure precedes the onset of nitrogen narcosis, making the temporal dynamics of excitation and narcosis a particularly interesting subject for further study.

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