Integrated monitoring of vestibular function, air-sickness and spatial disorientation in the Swiss airforce

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Problem definition

In-flight motion perception → disorienting visuo-vestibular stimuli

Effects:

- Spatial disorientation, motion sickness, sopite syndrome
- aberrant eye reflexes (e.g. incorrect targeting, blurred vision)
- cognitive impairment (e.g. +10% cognitive errors, slower reaction time)

Consequences:

- direct high-risk – fatal maneuvers
- risks for subtle/unrecognized form (e.g. sopite syndrome[1])
- impaired **performance** (e.g. +10% wrong decision)

Actual impact?

1 – **Sopite syndrome**: form of motion sickness with no evident signs (nausea or vomit) but **causing unrecognized profound drowsiness and performance loss**. It is recognized as cause of accident.

Spatial disorientation (SD)

- Spatial disorientation is a condition elicited by an “unnatural/unknown” self-motion stimuli (including illusion of motion)

- Incapacity to determine correctly
  - position and orientation in space (3DoF in a given reference frame)
  - self-motion status (6 DoF in physics – perceptually more)

- **Disorientation is not simply confusion!**
  - A possible interpretation of the sensory inputs might be present, but wrong (e.g. illusion in aviation)

Motion sickness (MS)

- Motion sickness (Air-) is a syndrome elicited by **sustained** "unnatural/unknown" self-motion stimuli (including illusion of motion)

- Motion sickness is elicited by **a "conflict"** among different motion-sensitive input

- **Motion sickness is more than nausea and vomiting!**
  - Yawning, sweating, deregulation of body temperature, headache, bradycardia, transient cognitive impairment, performance drop, slower reaction time, apathy

Incidence and conditions - 1/2

They occurrence is hard to predict, but there are known triggering conditions

- External factor: Atmospheric conditions, flight maneuvers, use of HUD/NVG,…
- Internal factors: fatigue, distractors, crew-coordination, experience, training…

Preliminary Survey of Spatial Disorientation in UK Military Pilots and Navigators

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USAF Spatial Disorientation Survey

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Spatial Disorientation Survey Among Military Pilots

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BACKGROUND: Spatial disorientation (SD) remains a significant cause of accidents and near accidents. A variety of training methods have been used to assist pilots to anticipate the SD problem. The value of such training in the prevention of disorientation has been difficult to assess.

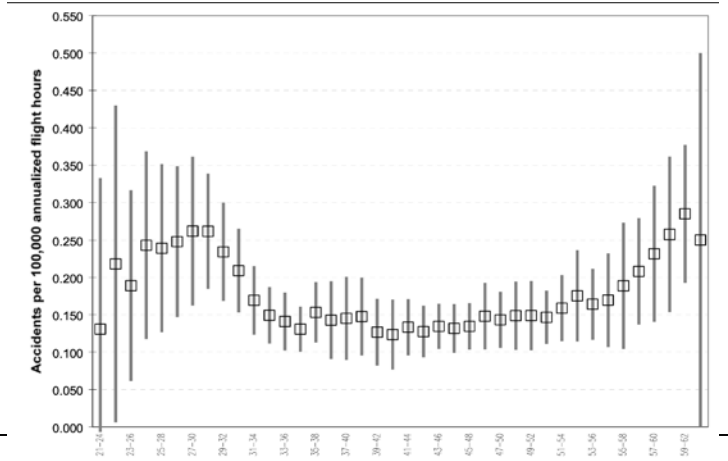
METHODS: To study transfer of SD awareness training, we related reported incidents to the content and frequency of SD awareness training received. The questionnaire was completed by 368 out of 495 pilots; 189 currently flying fixed-wing, and 150 flying rotary-wing aircraft. On average, their age was 38, and they had 2466 flight hours on-type.

RESULTS: Respondents gave high ratings for the importance of SD training and their awareness of SD, the latter being one of the

Incidence and conditions - 2/2

Post-flight analysis of accidents/episode is influenced by pilot career stage

- in trainee pilots:
  - due to experience/adaptation to new flight conditions
- in expert pilots:
  - may be considered consequent to change in the visuo-vestibular processing due to adaptation, aging or acute vestibular insults



Broach et al. 2003, Pilot Age and Accident Rates Report 3, Civil Aeromedical Institute Oklahoma City

Swiss Air Force MS/SD management

The Swiss Air Force manages these episodes with a three steps plan:

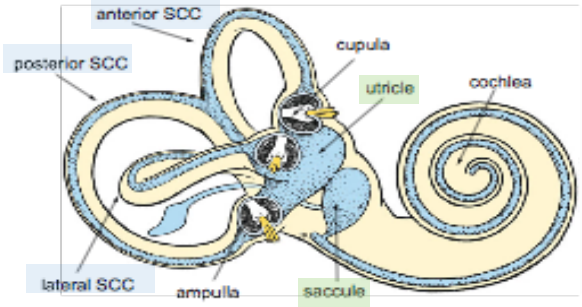
1. **STEP 1:** Clinical assessment of neuro-vestibular function
2. **STEP 2:** Assessment of sensitivity to vestibular and visual stimulation and non-clinical vestibular assessment (e.g VOR/OKAN time constant);
3. **STEP 3:** Visual/vestibular desensitization procedures

Clinical assessment (Step 1) - 1/3

STEP 1: Clinical assessment of neuro-vestibular function

semicircular canals

- video head-impulse test
- caloric ear irrigation test
- dynamic visual acuity



Obrist et al. 2010

angular acceleration

otolith organs

- subjective visual vertical
- fundus photography
- cervical vestibular-evoked myogenic potentials (cVEMPs)
- ocular vestibular-evoked myogenic potentials (oVEMPs)

linear acceleration

Clinical assessment (Step 1) - 2/3

STEP 1: Clinical assessment of neuro-vestibular function

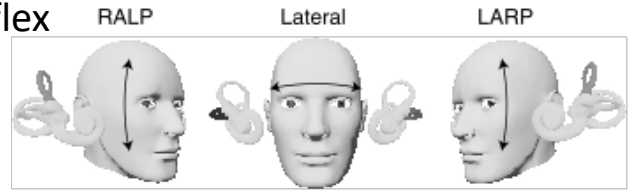
semicircular canals

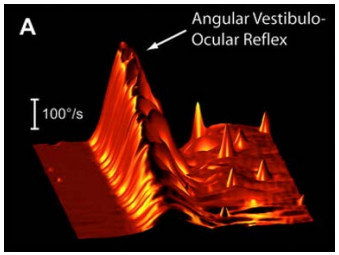
- **video head-impulse test**
- caloric ear irrigation test
- dynamic visual acuity

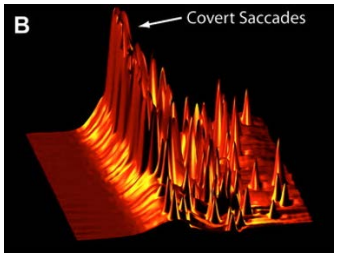
angular acceleration

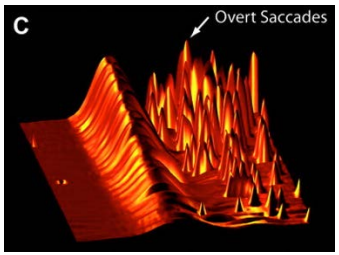
- not invasive
- measures canal-specific gains of the vestibulo-ocular reflex (VOR)
- detects covert catch-up saccades

eye: video
head: accelerometer









MacDougall, Weber et al. 2008-2013

Clinical assessment (Step 1) - 2/3

STEP 1: Clinical assessment of neuro-vestibular function

semicircular canals

- video head-impulse test
- **caloric ear irrigation test**
- dynamic visual acuity

angular acceleration

COWS Method:

- Cold Other side
  Warm Same side

Eye recording

- Video Oculography

Clinical assessment (Step 1) - 2/3

STEP 1: Clinical assessment of neuro-vestibular function

semicircular canals

- video head-impulse test
- caloric ear irrigation test
- **dynamic visual acuity**

angular acceleration

- Recognition of the symbols (visual acuity) during head impulses (> 150º/s, 100 ms)

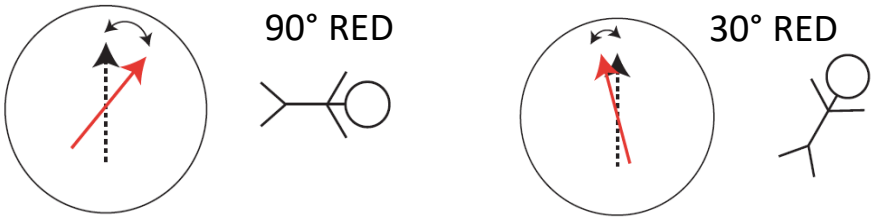
- Functional test of vestibulo-ocular reflex
- Complementary to head impulse test

Vital et al. 2010

Clinical assessment (Step 1) - 3/3

STEP 1: Clinical assessment of neuro-vestibular function

- Assessment of Perceived vs true earth-vertical
- Aligning a luminous line with the perceived earth-vertical in otherwise complete darkness



RED = right ear down

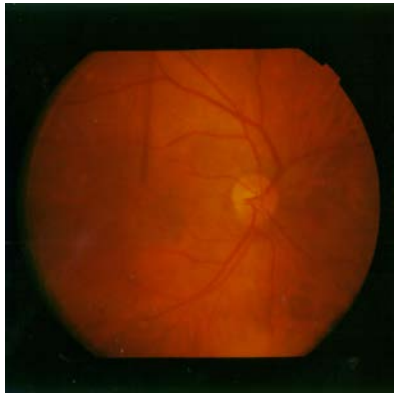
otolith organs

- **subjective visual vertical**
- fundus photography
- cervical vestibular-evoked myogenic potentials (cVEMPs)
- ocular vestibular-evoked myogenic potentials (oVEMPs)

linear acceleration

Clinical assessment (Step 1) - 3/3

STEP 1: Clinical assessment of neuro-vestibular function



otolith organs

- subjective visual vertical
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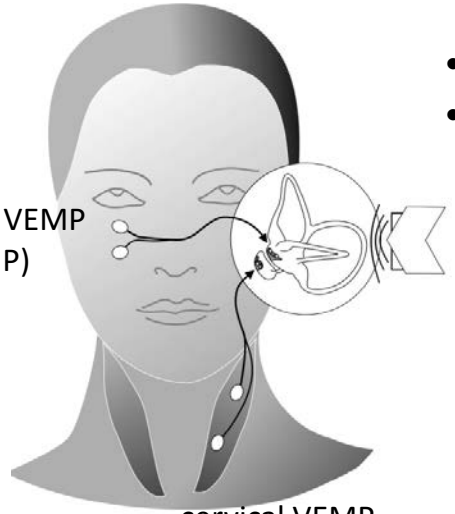
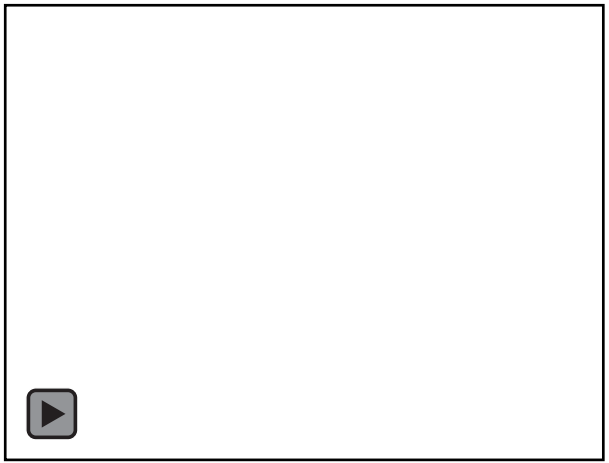
Clinical assessment (Step 1) - 3/3

STEP 1: Clinical assessment of neuro-vestibular function



Büki & Tarnutzer 2014

- Test of oVEMP and cVEMP
- Sound evoked or vibration evoked



otolith organs

- subjective visual vertical
- fundus photography
- **cervical vestibular-evoked myogenic potentials (cVEMPs)**
- **ocular vestibular-evoked myogenic potentials (oVEMPs)**

linear acceleration

Assessment of MS sensitivity

STEP 2: Assessment of sensitivity to vestibular and visual stimulation and non-clinical vestibular assessment (e.g VOR/OKAN time constant);

Turntable test with video-oculography:

1. **Coriolis and Pseudo-coriolis stress-test**

2. **Vestibulo-ocular reflex (VOR)**
   - Chair rotation in darkness (60°/s)
3. **Optokinetik after nystagmus (OKAN)**
   - Chair stays steady. Drum rotation in light (60°/s - 30 s) and then sudden darkness

Coriolis Stress Test

STEP 2: 1) Coriolis and pseudo Coriolis stress test

Up to 4 repetition of 4 head tilts (with 10 sec break between tilts)

- During rotation at 90°/s in darkness (Coriolis)
- During visual rotation (drum rotation/chair steady) at 60°/s in light

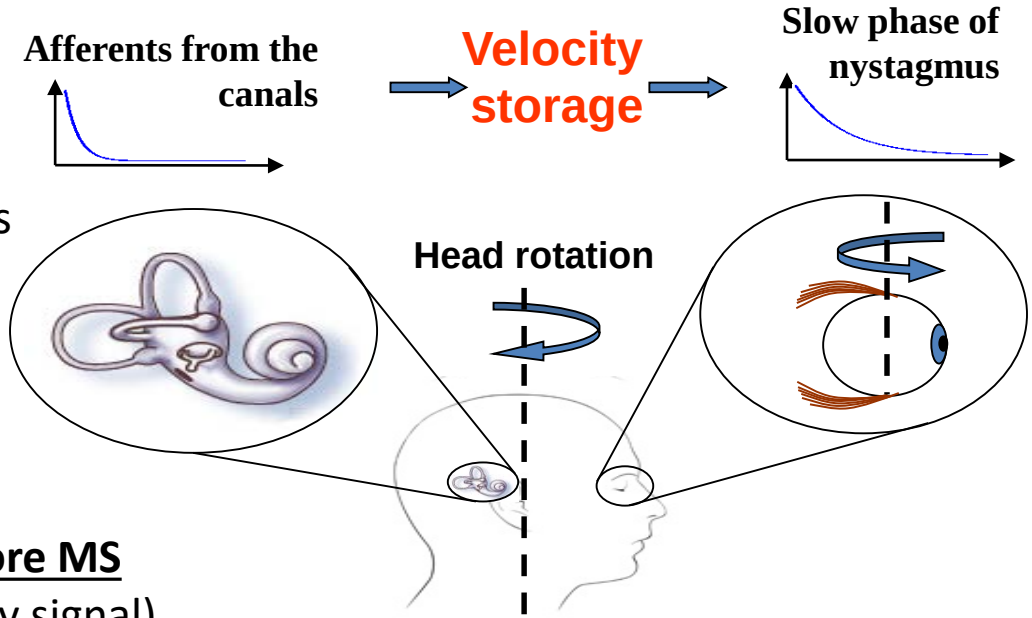
Motion sickness score (0-20) after each series of 4 head tilts

VOR Assessment - 1/2

STEP 2: 2) Velocity step response of vestibulo-ocular reflex (VOR)

Constant vel. rotation in darkness:

- Eye velocity decreases slowly,
  but:
  - Canals response decays in 10-20 s
    (Time constant ~ 6 s)
  - rVOR response decays in 45-60 s
    (Time constant ~ 15 s)

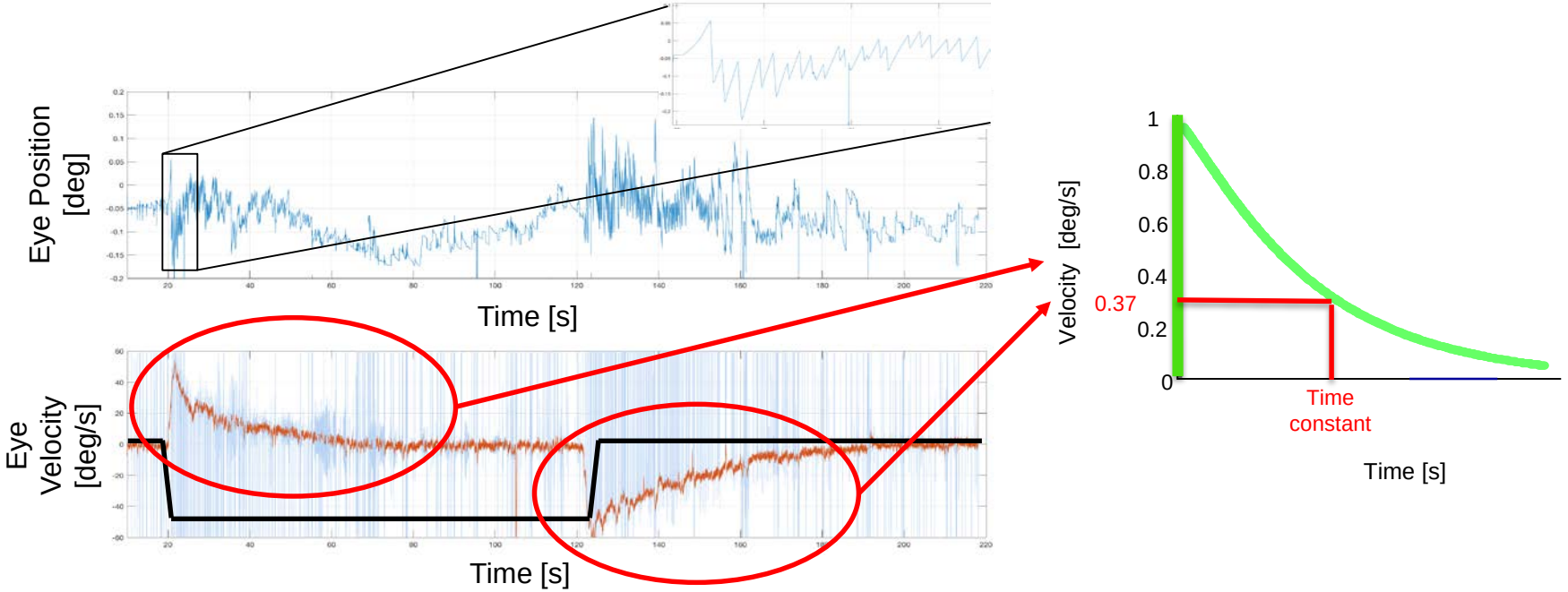


- **<u>Longer rVOR time constant = more MS</u>**

(i.e. longer "prolongations" of sensory signal)

VOR Assessment - 2/2

STEP 2: 2) Velocity step response of vestibulo-ocular reflex (VOR)



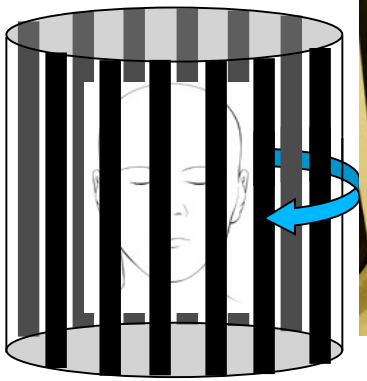
OKAN Assessment - 1/3

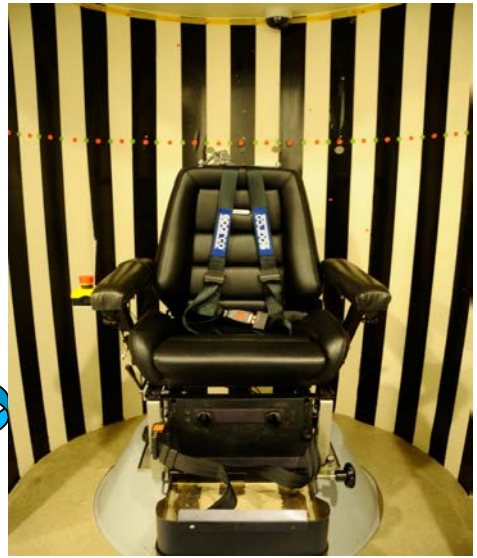
STEP 2: 3) Optokinetic nystagmus and afternystagmus (OKN/OKAN)

A full-field rotation of the visual field induce a nystagmus.

- Eye velocity decays slowly when switching the light off
- **Longer time constant of decays is related to visual induced MS**

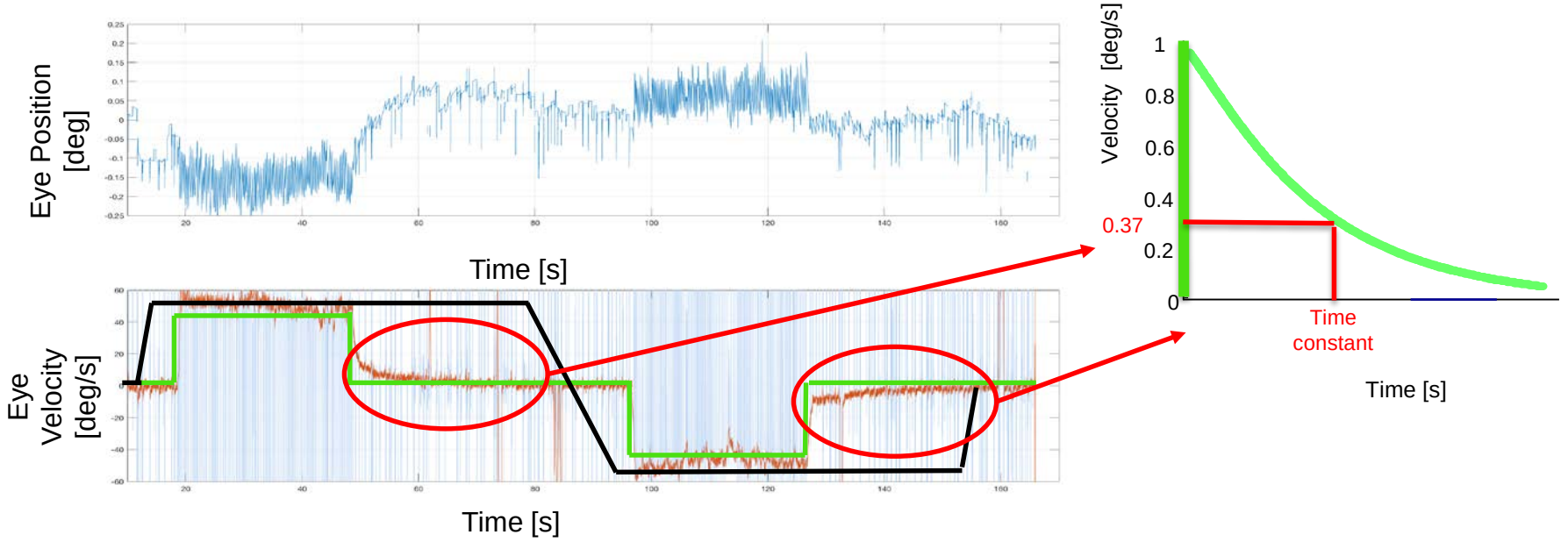
  (Guo et al. 2011, Bertolini et al. 2021)





OKAN Assessment - 2/3

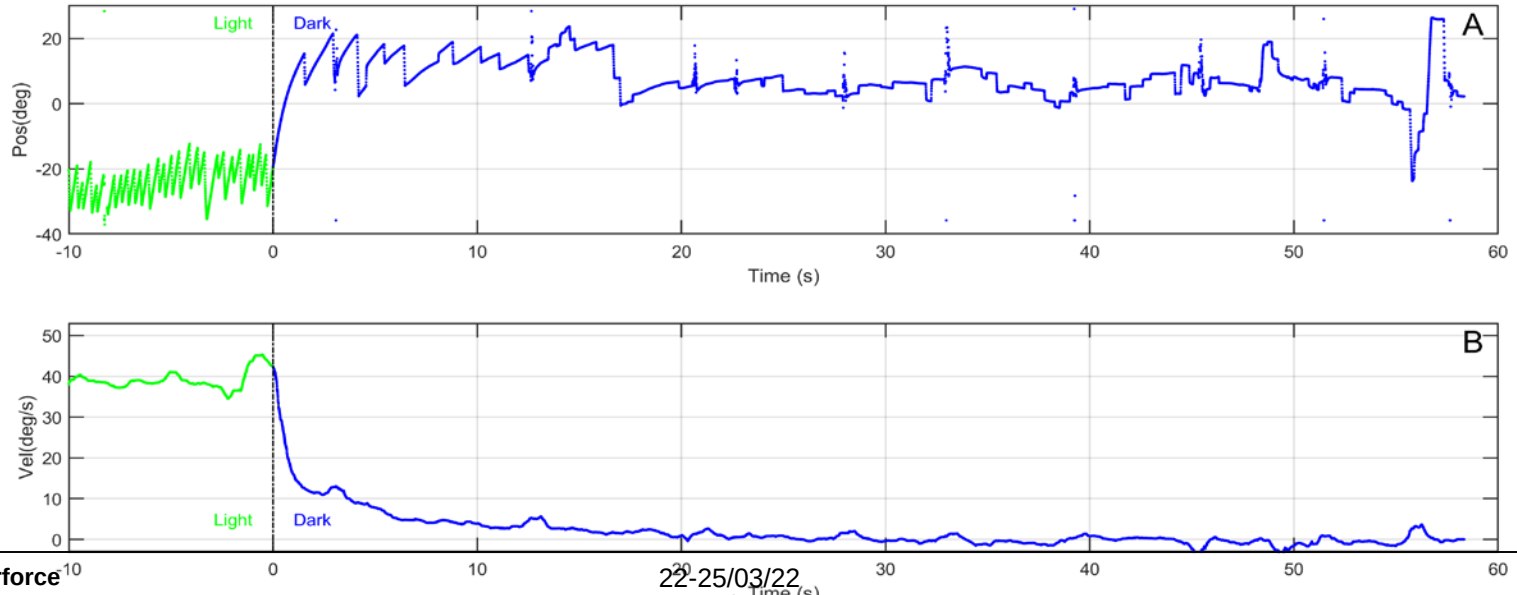
STEP 2: 3) Optokinetic nystagmus and afternystagmus (OKN/OKAN)



OKAN Assessment - 3/3

STEP 2: 3) Optokinetic nystagmus and afternystagmus (OKN/OKAN)

Normal OKAN response



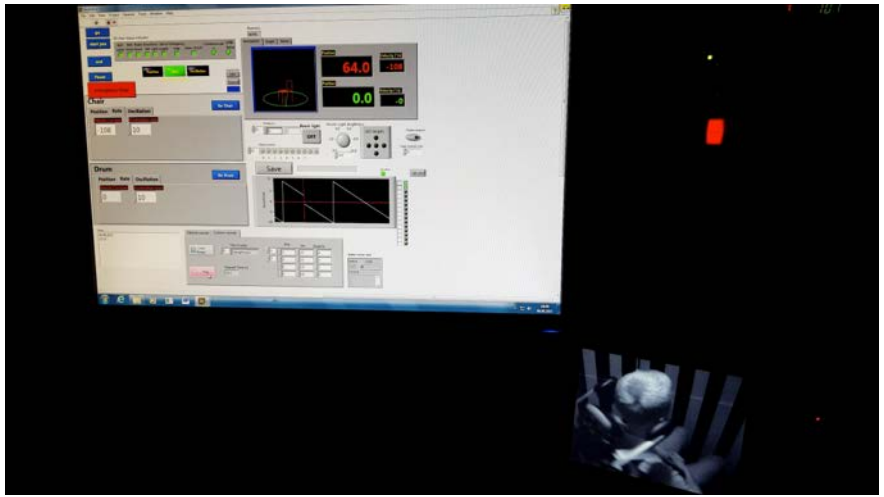
Desensitization

STEP 3: Visual/vestibular desensitization procedures

Head tilts while rotating in darkness or with visual rotations

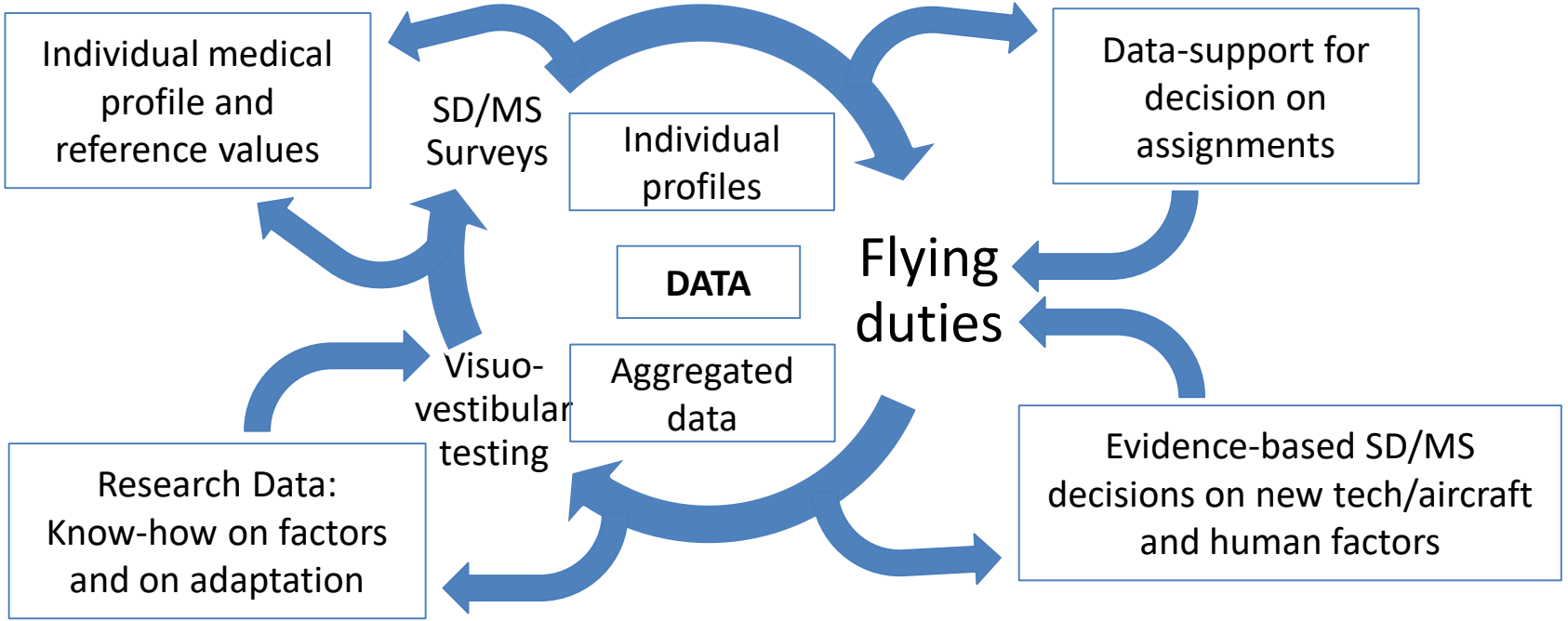
- 5 days; 2x day, 1 hour
- Increments of head tilt size and speed from 6 deg/s to 150 deg/s
- 10 repetitions of 4 tilts and MS score lower than subjective threshold
  → Step up

Video



PLAN: New integrated strategy - 1/3

A new strategy for management of airsickness and spatial disorientation



PLAN: New integrated strategy - 2/3

A **personal** visuo-vestibular and oculomotor performance profile integrating:

objective clinical data & SD/MS survey for follow-up

Aim is to **support** developments in each career phases, **not to stop them**

1. A personal visuo-vestibular profile is created in after recruiting to offer
   - case-specific **desensitization** when needed **to avoid career slow-down**
   - baseline data and reference values for visuo-vestibular and oculomotor tests
2. A monitoring plan that keep the the profile up-to-date
   - to **preventively** recognize emerging risk due to e.g. age, exposure…
   - to respond **objectively** to the pilots' requests, worries or needs
   - to optimize **context-/pilot-specific** assignments (e.g. in relation of with tech/aircraft type, flying condition) and reducing risks.

PLAN: New integrated strategy - 3/3

A **global database** of visuo-vestibular and oculomotor data integrating:

objective clinical data & SD/MS survey and incidence data

Aim is **provide** data to researchers and decision makers regarding

1. evidence-based risk factors associated with
   - introduction of **new technology** and their dependency on **human factors**
   - **repetitive exposure to flight conditions, adaptation, aging** in relation to objective changes in clinical data
2. improvements of selection criteria or trainings
   - to **preventively** control risk due SD
   - to reduce cost due to e.g. career breaks, later desensitization,…

Collaborations

University of Zurich -

Department of Neurology

University of Applied Science and Art – Institute of Optometry

University of Applied Sciences and Arts Northwestern Switzerland
School of Engineering

Swiss Space Travel and AiR Sickness Lab

Challenges

- Frequency of testing
  - age dependent, exposure dependent,…
  - minimal interference in duties…
- Global findings vs individual findings…
  - Proper interpretation, spurious findings
- Use of outcomes…
  - Stress of exclusion, judgment…


Thank you for your attention!