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Therapeutic effects of large-field visual virtual immersion on balance control in unilateral vestibular patients

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INTRODUCTION | VR-based balance rehab. relevance ?

1. NORMAL BALANCE CONTROL

Balance processes use visual, vestibular and proprioceptive sensory signals in a synergistic way. [1]

2. WHEN VESTIBULAR LOSS

Vestibular deficit increases a visual dependency due to the vestibular inhibition suppression [2].

3. OBJECTIVES

- Therapeutic effects of virtual reality (VR) based protocols (optical flows) to restore the reciprocal visual-vestibular inhibition, during a short rehabilitation period [3].

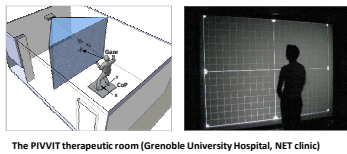
VR REHABILITATION

- Automatic sensory and motor compensations occur (visual-vestibular-motor) to reduce the patients' visual dependence.

METHODS | The PIVVIT project (Plateforme d'Immersion Visuelle Virtuelle Thérapeutique)

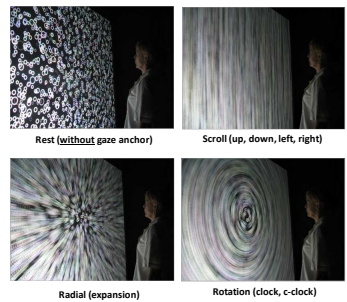
CLINICAL TRIAL - PATIENTS

- Unilateral vestibular patients (42-80 y.o. ; 3 m., 4 f.)
- Visually-induced dizziness (areflexia, chronic recurrent dizziness, vestibular neuritis)
- 8 weeks rehab. period = 1 or 2 rehab. session per week included in the patients care process
- Ethics validation (CPP - voluntary informed patients)



VISUAL STIMULI

- Large-field (panoramic) visual virtual flows
- Standardized optokinetic stimulus
- 8 Optical flows STIM. : 1D scrolls (Up, Down) + 2D Rotations (Clockwise, Counterclockwise) + 3D Radial expansion.
- 6 flows SPEED (speed ratio from s03 to s28 A.U.)
- Scenarii optimized for efficiency on patient : visual-flows constrains increase throughout the therapeutic session : flows pattern (scroll, radial and rotation), stimulation speed increased, gaze anchoring on the visual reference (with/without).



GAZE ANCHORAGE (GA)

- Visuo-spatial reference
- With GA : session 1-4 ; Without GA : session 5-8
- [With : session 9 ; Without : session 10]



PROTOCOL

> 1 Trial = Visual stimulation
 • Rest – Flow – Rest : 25 sec.

> 1 Serie = 8 stim. (8 trials)
 • 5 different 1D/2D-3D visual flows

> 1 Session = 6 Speed
 • 8 trials x 6 speed = 48 trials

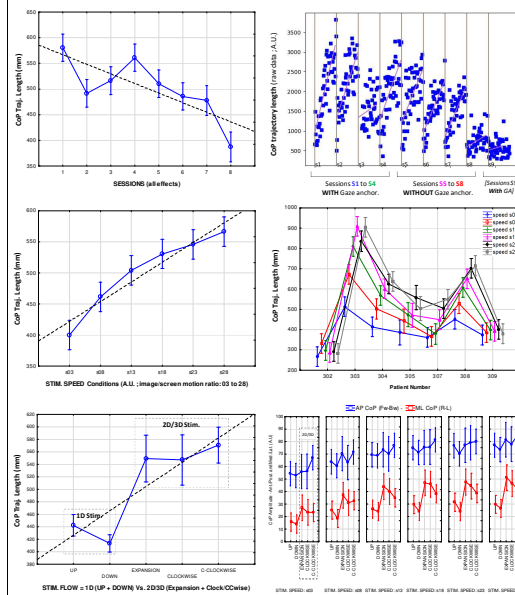
> 2 Gaze Anchorage cond.
 • Sess. 1-4 : With GA
 • Sess. 5-8 : Without GA
 = (48 trials x 8) = 384 trials (x 15sec.)
 → Total stim. duration = 96 min. (1h36)

> [2 Phases = Compar./Valid.]
 • 8 VR-based sess. (PIVVIT) → "Proof of concept"+++
 • 8 Standard OKS sess. → "Proof of non-inferiority"+++

DATA RECORDING AND ANALYSIS

- Balance control : Center-of-Pressure (Wiifit board, 100 Hz) : **CoP Trajectory length** → Disequilibrium indicators (lost of balance control, falls)
- Gaze behaviour (**Eye-Head-(body) stability**) ; BlueGain EOG, 100Hz) : **EOGxy trajectory** (preliminary results)
- [Questions-Responses (subjective estimation of the "balance comfort" in every day life tasks)]

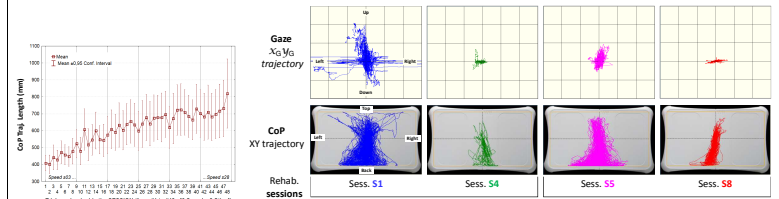
RESULTS | VR immersion → Visual perturbation → Balance restoration



INTER-SESSIONS effect (representative patient)
 → Decreases the CoP Trajectory length
 → Reduces the postural reaction
 → Decrease the balance perturbation
 → Improve the Gaze-Balance interactions

Flows SPEED effect (all patients)
 → Increase the CoP Trajectory length
 → Increase the balance perturbations
 → Stimulate the compensatory postural adjust.

[SPEED x STIM.] effect on AP-ML adjustments (all patients)
 → [Speed max. + 2/3D stim.] > [Speed min. + 1D stim.]
 → High [Speed x Stim.] increase the CoP Trajectory length → related to the augmented complexity of the virtual stim.
 → Increase the balance perturbations
 → Multiple visual flows parameters "co-stimulate" the compensatory postural strategies



INTRA-SESSIONS effect (all patients)
 → Increase the CoP Trajectory length
 → Increase of the postural reaction
 → "Positive fatigue effect" ? → **Optimal Difficulty Level?**

GAZE-BALANCE INTERACTION (representative patient)
 → Functionally (neuro-mechanically!) coupled and synchronized
 → Synergistic improvement and interactive stabilisation
 → Gaze OR Balance enhancement ... ocular OR vestibular efficiency thanks to the visual-retinal flows ... Which sub-system drives the improvement ?

DISCUSSION – CONCLUSION | Rapid VR-based rehab. benefits

At a Clinical/Rehab. level : Positive effects of the "large visual field" immersion on balance restoration

- METH.** Patient-related sessions repetition + difficulty-dependent tuneable scenarios + patient follow-up + methodical practice through short period (two months)
- BENEFITS.** Rapid functional restoration of efficient synergistic control between balance and gaze process.
- PSYCHOL.** Patients' motivation and self-confidence !

At a Neuro-functional level : "visual-vestibular-motor" adaptation occurs despite the vestibular deficits

- PROCESS.** Reweighting of the visual-vestibular sensory inputs → reciprocal inhibition restoration
- ADAPTATION.** Reduction of the visual dependence by visual-vestibular reverse compensations

→ **Questions about the neural basis of the "visual-vestibular plasticity"**

- Sensory adaptive threshold/gain of the VOR and/or OKN ?
- Dual sensorimotor plasticity in balance restoration : Interaction MT visual area - vestibular nuclei → visual-vestibular integration for motor command and tuning/adjustment.

CONCLUSION

- Optimized rehabilitation strategies based on simple virtual visual immersions Vs. standardized rehabilitation protocols (uncontrolled OKS) for unilateral vestibular patient
- Limit: No long-term effects** (reported by patients after a six months period) requiring periodic booster sessions
- **Our study corroborate the proof of concept of interactive VR-rehabilitation based on a large visual field stimulation device (experimental and clinical validation).**