

CHERCHONS
**POUR
VOIR**



Plateforme de recherche
technologique au service
des déficients visuels



<http://www.irit.fr/~Christophe.Jouffrais>

Les neuroprothèses visuelles basse-résolution sont-elles utilisables?

Christophe Jouffrais

IRIT-ELIPSE

Laboratoire Commun IRIT-IJA

Journées Neurostic 2015

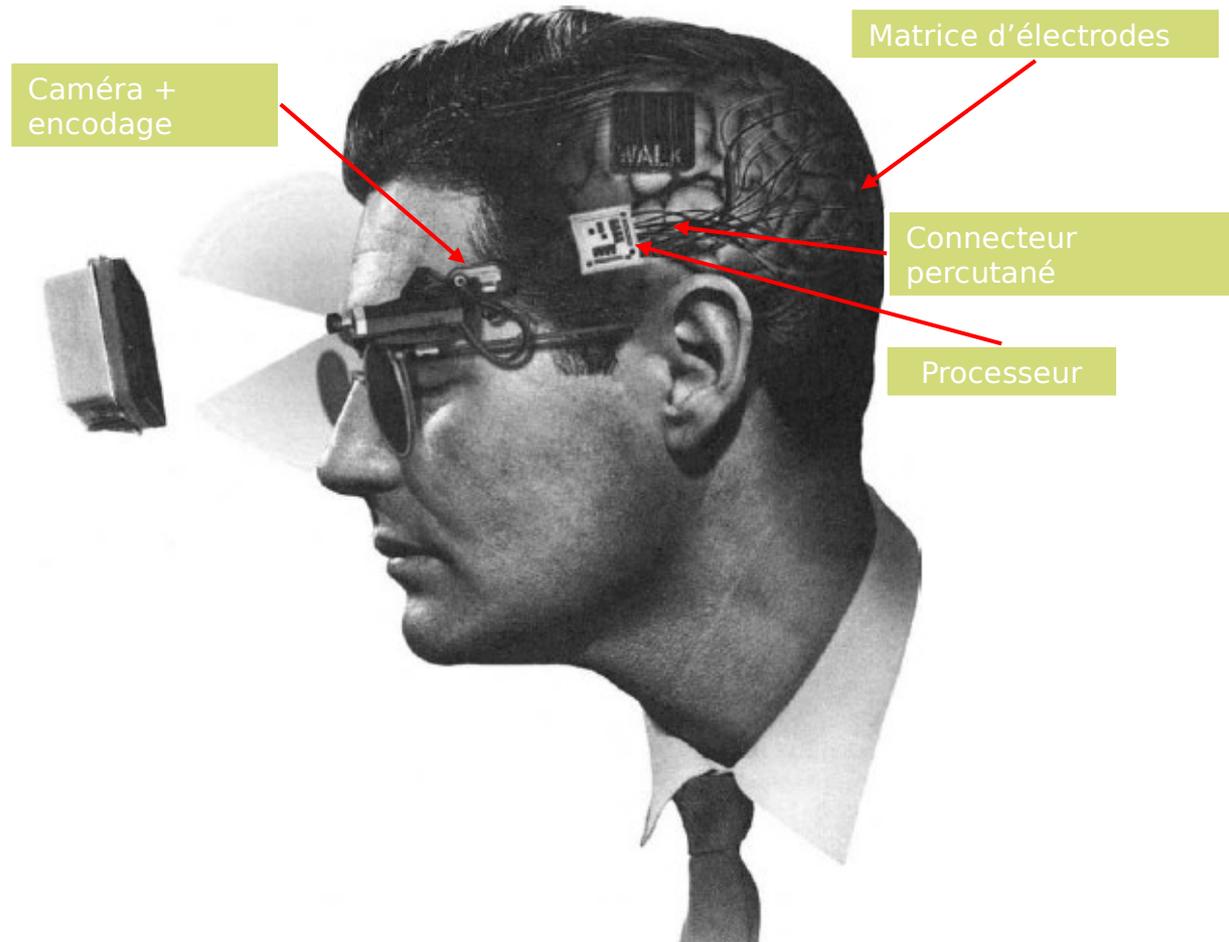
Malvoyance et cécité

- ▶ OMS : 315 millions des personnes déficientes visuelles dans le monde
 - ▶ dont près de 45 millions d'aveugles
- ▶ 85% dans les pays en développement
- ▶ 4 non-voyants sur 5 ont plus de 50 ans
- ▶ Doublement prévu en 25 ans avec le vieillissement des populations



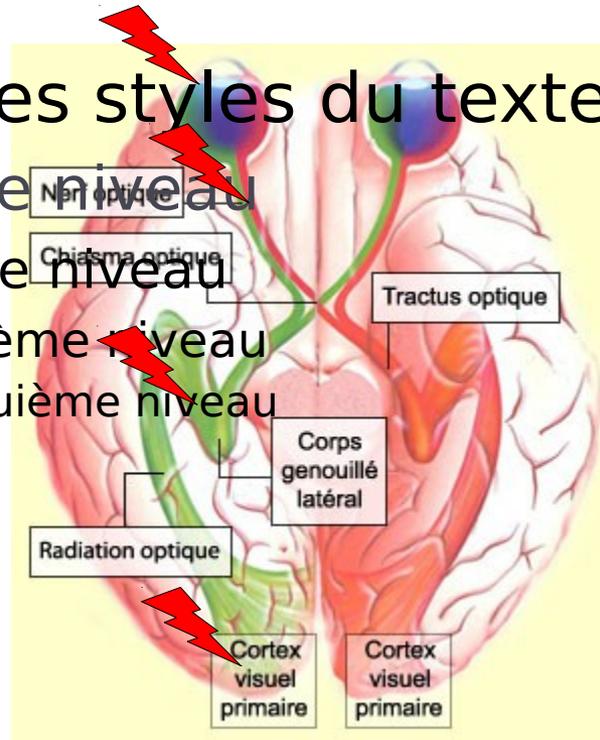
Les NeuroProthèses Visuelle (NPV)

Principe de la vision neuroprothétique



Les sites d'interface

- ▶ Modifiez les styles du texte du masque
 - ▶ Deuxième niveau
 - ▶ Troisième niveau
 - Quatrième niveau
 - Cinquième niveau



The sensations produced by electrical stimulation of the visual cortex

G. S. Brindley and W. S. Lewin J. Physiol. 1968



Fig. 1.



Modifiez les styles du texte du r

Deuxième niveau

Troisième niveau

□ Quatrième niveau

□ Cinquième niveau



The sensations produced by electrical stimulation of the visual cortex

- ▶ Brindley and Lewin J. Physiol. 1968
- ▶ The sensations produced by electrical stimulation of the visual cortex
 - ▶ Array of radio receivers
 - ▶ 52-year-old blind patient.
- ▶ Sensation caused is a single very small spot of white light at a constant position in the visual field
- ▶ Duration and frequency of stimulating pulses have been explored.
- ▶ Phosphenes ordinarily cease immediately when stimulation ceases, but after strong stimulation they sometimes persist for up to 2 min.
- ▶ **Our findings strongly suggest that it will be possible, by improving our prototype, to make a useful prosthesis.**

TABLE 2. The relation between frequency and threshold potential for electrode 19 of Text-figs. 1 and 2, measured with pulses of duration 30 μ sec

Frequency (pulses/sec)	Threshold (V)	Frequency (pulses/sec)	Threshold (V)
25	29	400	35
50	27	630	37
100	21	1000	39
160	21	1600	35
250	25	4000	29
400	27		28
630	10		36
1000	13		56
1600	10		
4000	15		

Quatrième niveau
Cinquième niveau

Approches rétiniennes

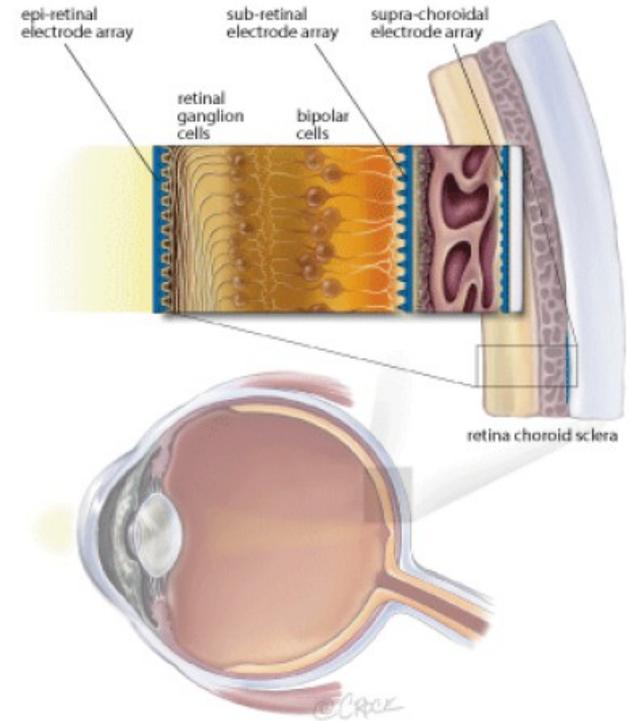
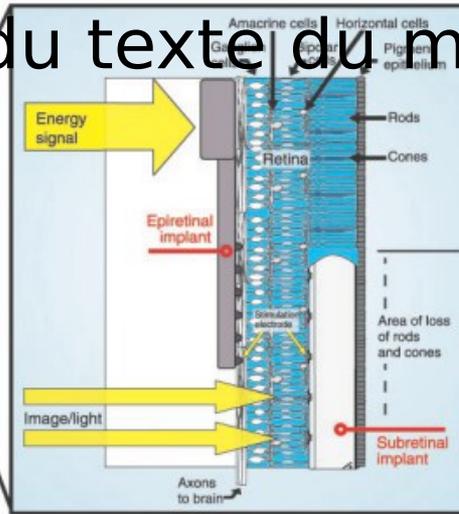
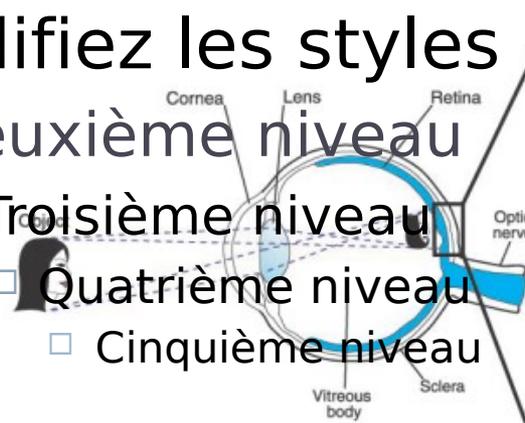
Modifiez les styles du texte du ma

▶ Deuxième niveau

▶ Troisième niveau

□ Quatrième niveau

□ Cinquième niveau



130 millions de photorecepteurs
1,2 millions de cell ganglionaires
Sub □ photodiodes
Epi □ camera

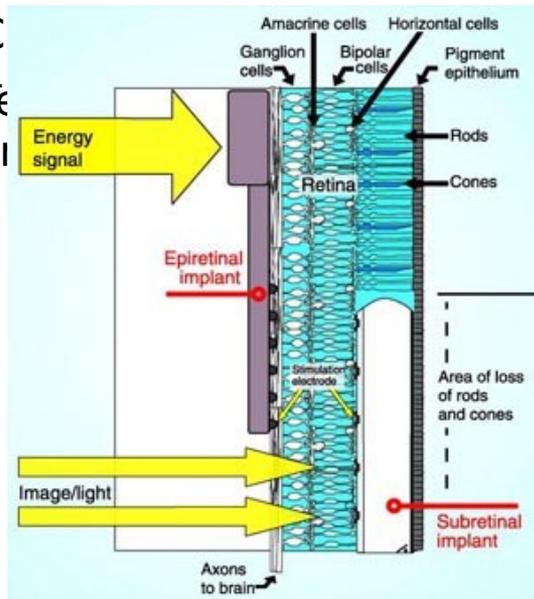
From Zrenner 2003

Interfaces rétiniennes - [Zrenner Science 2002]

Implants épirétiniens (cf. Argus 2)

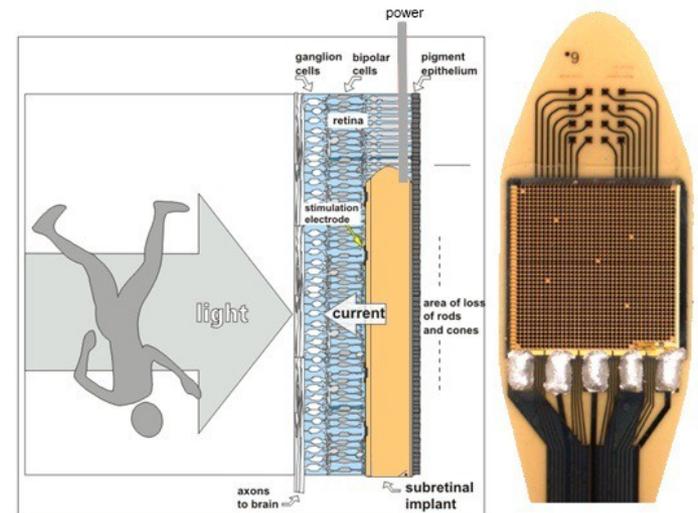
- ▶ [Wyatt & Rizzo 1996; Eckmiller, 1997]
- ▶ sur la surface vitrée
- ▶ Caméra et stratégies de codage nécessaires

- ▶ C
- ▶ Te
- ▶ li



Implants subrétiniens

[Chow & Chow, 1997; Zrenner et al., 1997]
entre la rétine et l'épithélium pigmentaire
100nes à 1000ers d'électrodes
50 à 150 um entre electrodes
Microphotodiodes remplacent les récepteurs
mais énergie supp nécessaire
Peu de contraintes chirurgicales et
mécaniques
Optique de l'œil OK
Test animaux: 16 mois



Argus II (épirétinien): 60 électrodes

Argus II Retinal Prosthesis System - H110002

This is a brief overview of information related to FDA's approval to market this product. See the links below to the Summary of Safety and Probable Benefit Data (SSPB) and product labeling for more complete information on this product, its indications for use, and the basis for FDA's approval.

Product Name: Argus II Retinal Prosthesis System

HDE Applicant: Second Sight Medical Products, Inc.

Address: 12744 San Fernando Rd., Bldg #3, Sylmar, CA 91342

Approval Date: February 13, 2013

Approval Letter:

http://www.accessdata.fda.gov/cdrh_docs/pdf11/h110002a.pdf

What is it? The Argus II Retinal Prosthesis System is the first implanted device to treat adults with severe *retinitis pigmentosa*. The System has three parts: a small electronic device implanted in and around the eye, a tiny video camera attached to a pair of glasses, and a video processing unit that is worn or carried by the patient.

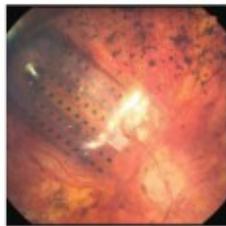


Figure 3-2 L'implant Argus II. Photo montrant la matrice d'électrodes fixée dans la rétine d'un patient. Cet implant épirétinien développé par la société Second Sight, mesure 4 x 5 mm et contient une matrice de 6 x 10 électrodes arrangées de façon rectangulaire. Les électrodes ont un diamètre de 200 µm. Elles sont séparées horizontalement et verticalement de 525 µm (centre à centre). La matrice couvre une diagonale d'environ 20° de champ de vision. (Source Zhou, Dorn, & Greenberg, 2013)

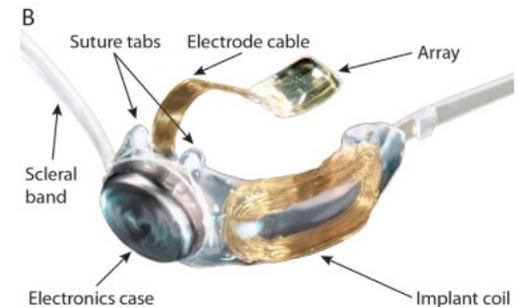
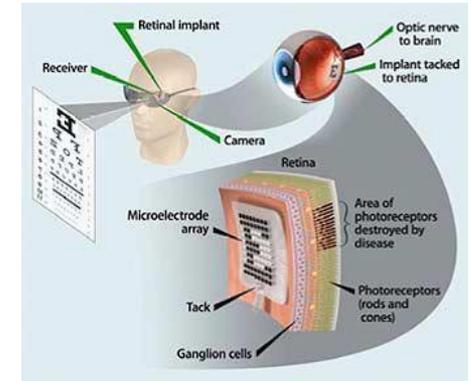


Figure 1. A, Photograph of the external portion of the Argus II prosthesis system (Second Sight Medical Products, Inc., Sylmar, CA) including glasses-mounted video camera, radio-frequency (RF) coil, and video processing unit (VPU) with rechargeable battery. B, Photograph of the implanted portion of Argus II prosthesis system including the 6x10 electrode array, electronics case, and implant RF coil.

Ex d'implant actuel

30 personnes équipées avec Argus 2 (6*10)

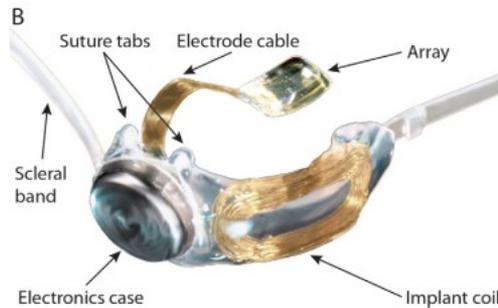
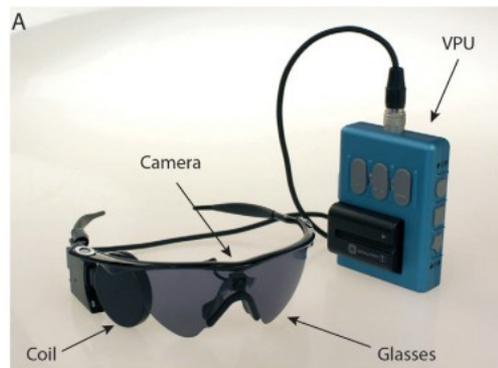


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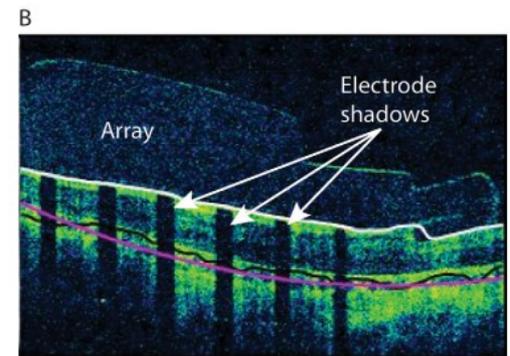
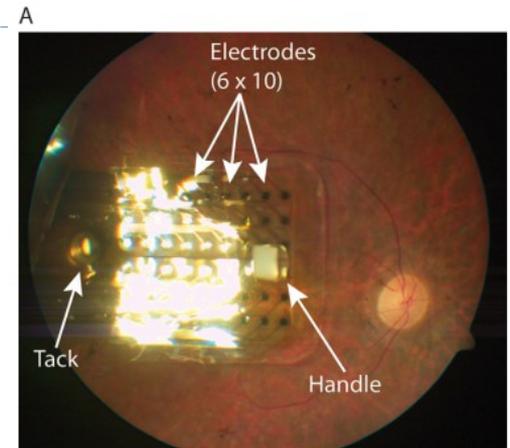


Figure 2. A, Fundus photograph of implanted Argus II array (Second Sight Medical Products, Inc., Sylmar, CA) in the macular region. The electrode array is secured to the retina with a retinal tack; the white square visible on the distal side of the array is an opaque section of tubing (the handle) used by the surgeon to position the array. B, Optical coherence tomography image of an implanted Argus II array. Shadows cast on the retinal image (white arrows) are the result of occlusion of the scanning light source by the metal electrodes.

Argus 2 en France

- ▶ Autorisé à la vente sur le marché européen depuis 2011
- ▶ Programme lancé en 2014 par ministère de la santé (Forfait Innovation)
- ▶ Financé par sécurité sociale pour 36 patients
- ▶ Forfait de prise en charge est fixé à 95.897 euros par patient
- ▶ patients sélectionnés selon des critères validés par la Haute Autorité de Santé (HAS) « bénéficieront ainsi gratuitement de ce dispositif médical sur une période maximale de cinq ans »
- ▶ Trois établissements hospitaliers
 - ▶ Centre hospitalier national d'ophtalmologie (CHNO) des Quinze-Vingts à Paris
 - ▶ Centres hospitaliers universitaires (CHU) de Bordeaux et Strasbourg
- ▶ Autre projet concurrent par Institut de la Vision
- ▶ <C:\Users\Christophe\Videos\Neuroprothèses\Visuelle>



Humayun et al, Ophthalmology 2012

► **Modifiez les styles du texte du masque** of Second Sight's Visual Prosthesis

► **Deuxième niveau**
► **Troisième niveau**
► **Quatrième niveau**
► **Cinquième niveau**

Mark S. Humayun, MD, PhD,¹ Jessy D. Linares, MD,² Lyndon da Cruz, MD, PhD,³ Gislin Dagnelie, PhD,⁴ José-Alain Sahel, MD,⁵ Paulo E. Stanga, MD,⁶ Artur V. Cideciyan, PhD,⁷ Jacque L. Duncan, MD,⁸ Dean Elliott, MD,⁹ Eugene Filley, PhD,¹⁰ Michael J. Greenberg, MD,¹¹ Avinoam B. Safran, MD,¹² Ariès Arditi, PhD,¹⁴ Lucian V. Del Priore, MD,^{4,15} Robert J. Greenberg, MD, PhD,² for the Argus II Study Group*¹

Purpose: This study evaluated the Argus II Retinal Prosthesis System (Second Sight Medical Products, Inc., Sylmar, CA) in blind subjects with severe outer retinal degeneration.

Design: Single-arm, prospective, multicenter clinical trial.

Participants: Thirty subjects were enrolled in the United States and Europe between June 6, 2007, and August 11, 2009. All subjects were followed up for a minimum of 6 months and up to 2.7 years.

Methods: The electronic stimulator and antenna of the implant were sutured onto the sclera using an encircling silicone band. Next, a pars plana vitrectomy was performed, and the electrode array and cable were introduced into the eye via a pars plana sclerotomy. The microelectrode array then was tacked to the epiretinal surface.

Main Outcome Measures: The primary safety end points for the trial were the number, severity, and relation of adverse events. Principal performance end points were assessments of visual function as well as performance on orientation and mobility tasks.

Results: Subjects performed statistically better with the system on versus off in the following tasks: object localization (96% of subjects), motion discrimination (57%), and discrimination of oriented gratings (23%). The best recorded visual acuity to date is 20/1260. Subjects' mean performance on orientation and mobility tasks was significantly better when the system was on versus off. Seventy percent of the patients did not have any serious adverse events (SAEs). The most common SAE reported was either conjunctival erosion or dehiscence over the extraocular implant and was treated successfully in all subjects except in one, who required explantation of the device without further complications.

Conclusions: The long-term safety results of Second Sight's retinal prosthesis system are acceptable, and most subjects with profound visual loss perform better on visual tasks with system than without it.

Financial Disclosure(s): Proprietary or commercial disclosure may be found after the references. *Ophthalmology* 2012;119:779–788 © 2012 by the American Academy of Ophthalmology.

Humayun et al, Ophthalmology 2012

“direction of motion test: indicate the path of a white line swept across a black background”

► Modifiez les styles du texte du masque

► Deuxième niveau

► Troisième niveau

► Quatrième niveau

► Cinquième niveau



Figure 4. Graph showing the mean response error for each subject on the direction of motion task, system on (filled diamonds) and system off (empty squares). Subjects are ordered along the x-axis from greatest difference between on and off performance to least difference. Single asterisks indicate subjects for whom the system on mean was significantly different (smaller) than the system off mean, and the double asterisk indicates a subject for whom system off was significantly different (smaller) than system on ($P < 0.05$, 2-tailed t test assuming unequal variances). Data are the latest available for each subject as of March 1, 2010.

Humayun et al, Ophthalmology 2012

“real-world utility test:
find a door across a room”

- ▶ Modifiez les styles du texte du masque
- ▶ Deuxième niveau
- ▶ Troisième niveau
- Quatrième niveau
- Cinquième niveau

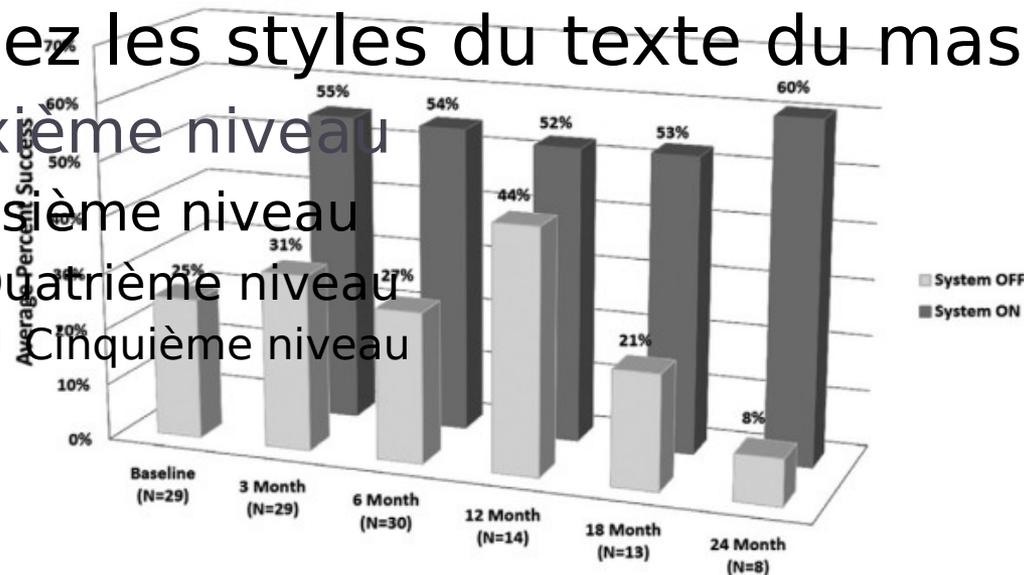


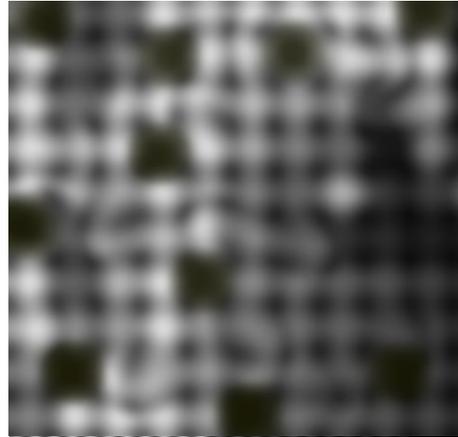
Figure 5. Bar graph showing the average percent success at each clinical visit for the find-the-door orientation and mobility task.

Problématique

Les interfaces neurales pour restaurer la vision? – Problématiques

1

- Représentation réduite à 625 pixels (25*25) ou 100 pixels



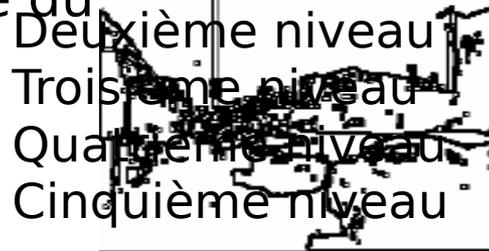
- Traitement de l'image (détecteur de bords par ex)

Modifiez les styles du texte du

- ▶ Deuxième niveau
- ▶ Troisième niveau
 - Quatrième niveau
 - Cinquième niveau

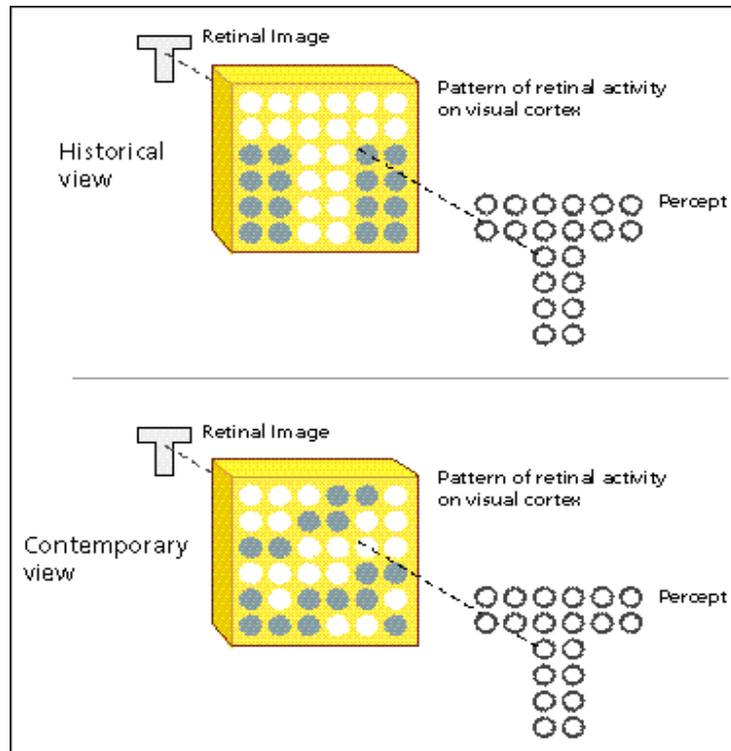


Modifiez les styles du texte du masque



Les interfaces neurales pour restaurer la vision? – Problématiques

2



3

Neurones visuels (rétine ou cortex) sont des intégrateurs d'indices :

- spatiaux
- temporels
- chromatiques
- binoculaires
- comportementaux

Non-conformité
Normann et al., Vis. Res. 2001

Simulation de NPV

Simulated Prosthetic Vision (SPV)

Modifiez les styles du texte du masque

Deuxième niveau

Troisième niveau

Quatrième niveau

Cinquième niveau



FIGURE 3. The visual phosphene simulator. The optical system is mounted on a pair of ski goggles which are occluded except where the screen of the video monitor (M) is placed. A lens placed in front of the video camera (C), which is mounted just above the monitor, controls the field magnification ratio. Lenses placed between the monitor and the subject's eye adjust the size of the visual field presented to the subject. The monitor is masked by an array of pinholes, so the image is composed of discrete spots of light. The device is portable and the subject can scan objects with head movements. The only visual input available to the subject is the image on the masked monitor. A battery belt (B) is worn around the waist so that the subject can move around freely.

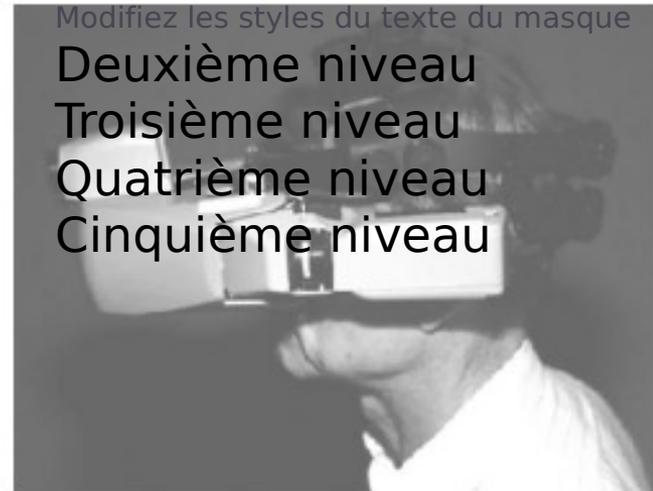


FIGURE 1. The LVES was worn by the subjects and used as a video projector to view the computer-generated reference and test images.

Thompson et al 03

Simulation of a Phosphene-Based Visual Field: Visual Acuity in a Pixelized Vision System

[Cha et al, Annals of Biomedical Engineering 1992]

Number of electrodes
Fixed-Field vs Fixed-spacing

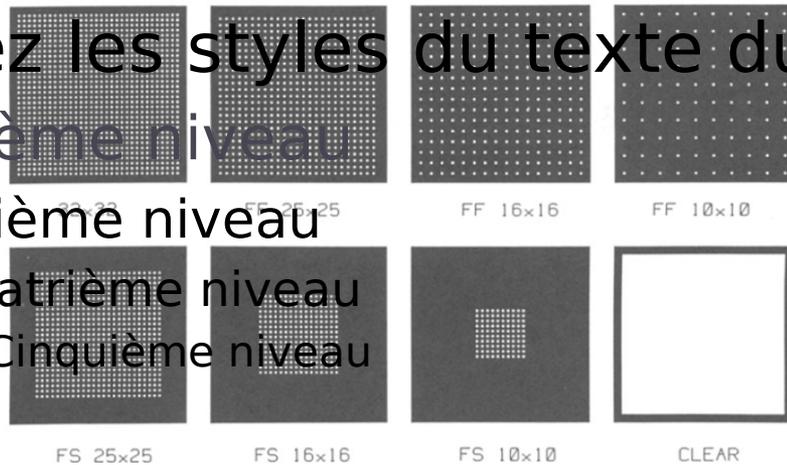


FIGURE 2. Masks used in the present study. The basic mask provided a 32×32 array of pixels, with a pixel spacing of twice the size of an individual pixel. Fixed-field (FF) masks covered the same visual angle as the basic mask, but spaced the pixels uniformly within this area. Fixed-spacing (FS) masks maintained the same spacing as the basic mask, but restricted the field size. The clear mask limited the visual field to the same visual angle as the FF masks.

“We conclude that **625 electrodes** implanted in a 1 cm by 1 cm area near the foveal representation of the visual cortex **should produce a phosphene image with a visual acuity of approximately 20/30**. Such an acuity could provide useful restoration of functional vision for the profoundly blind.”



FIGURE 3. The visual phosphene simulator. The optical system is mounted on a pair of ski goggles which are occluded except where the screen of the video monitor (M) is placed. A lens placed in front of the video camera (C), which is mounted just behind the monitor, controls the field magnification ratio. Lenses placed between the monitor and the subject's eye adjust the size of the visual field presented to the subject. The monitor is masked by an array of phosphene; as the image is composed of discrete spots of light, the device is portable and the subject can scan objects with head movements. The only visual input available to the subject in the image on the masked monitor. A harness belt (H) is worn around the waist so that the subject can move around freely.



FIGURE 4. An image viewed with different masks. The object was photographed directly from the simulator through a “clear” mask (A), a 32×32 mask (B), and a 16×16 fixed-field mask (C). The image size seen by the subjects is equivalent to the size of your thumb nail viewed at arm's length.

Simulation of a Phosphene-Based Visual Field: Visual Acuity in a Pixelized Vision System

[Cha et al, Annals of Biomedical Engineering 1992]

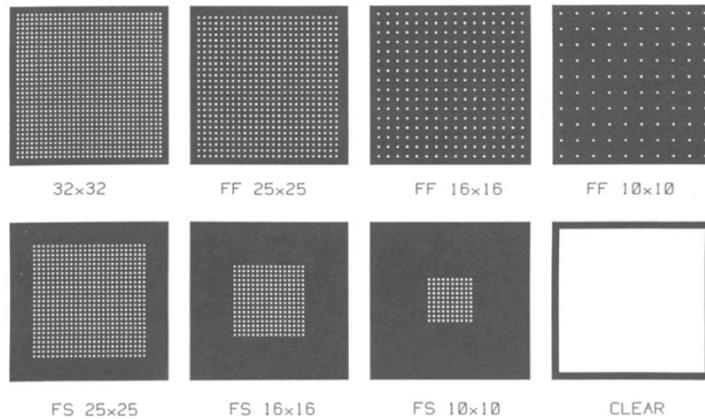


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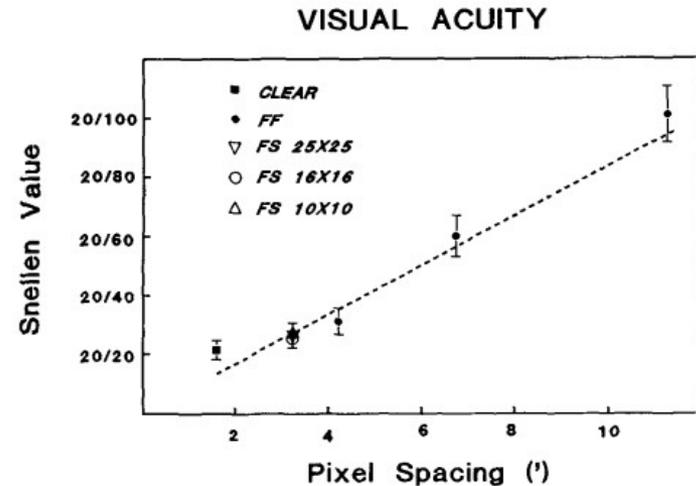


FIGURE 5. Average visual acuity, expressed as Snellen acuity, versus spacing between mask pixels (perforations), expressed in terms of subtended visual angle. The solid symbols show average values \pm standard deviations from the experiments in which the pixel spacing varied with pixel number (fixed-field masks). The open symbols show the results from experiments in which the pixel spacing was held constant while the number of pixels was varied (fixed-spacing masks). Fixed-field mask sizes were: clear (plotted as equivalent to a mask made up of fused pixels), 32×32 , 25×25 , 16×16 and 10×10 . The line shows expected acuity if the subject required a 2.1×2.1 pixel grid to recognize the orientation of the target letter.

Facial Recognition Using Simulated Prosthetic Pixelated Vision

[Thompson et al, IOVS 2003]

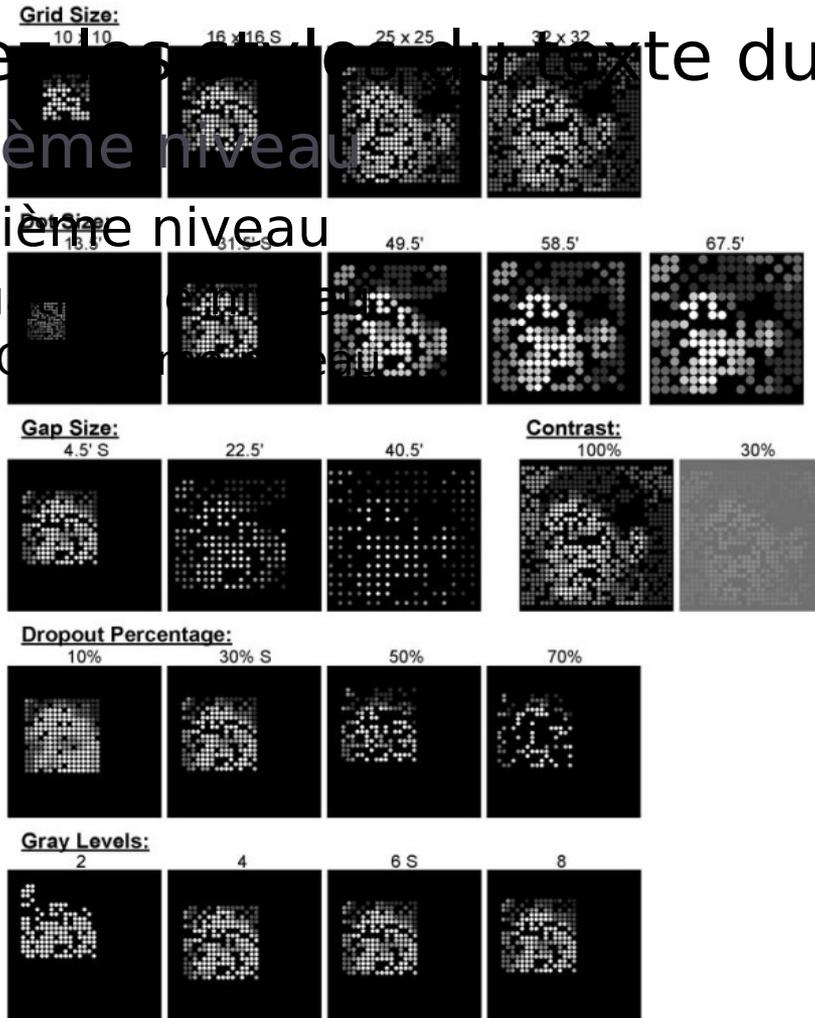
► **Modifier la taille du masque**

► **Deuxième niveau**

► **Troisième niveau**

□ **Qualité**

□ **Contraste**



Facial identification in very low-resolution images simulating prosthetic vision
Chang et al, J Neur Eng 2012

Modifiez les styles du texte du masque

Deuxième niveau

Troisième niveau

Quatrième niveau

Cinquième niveau

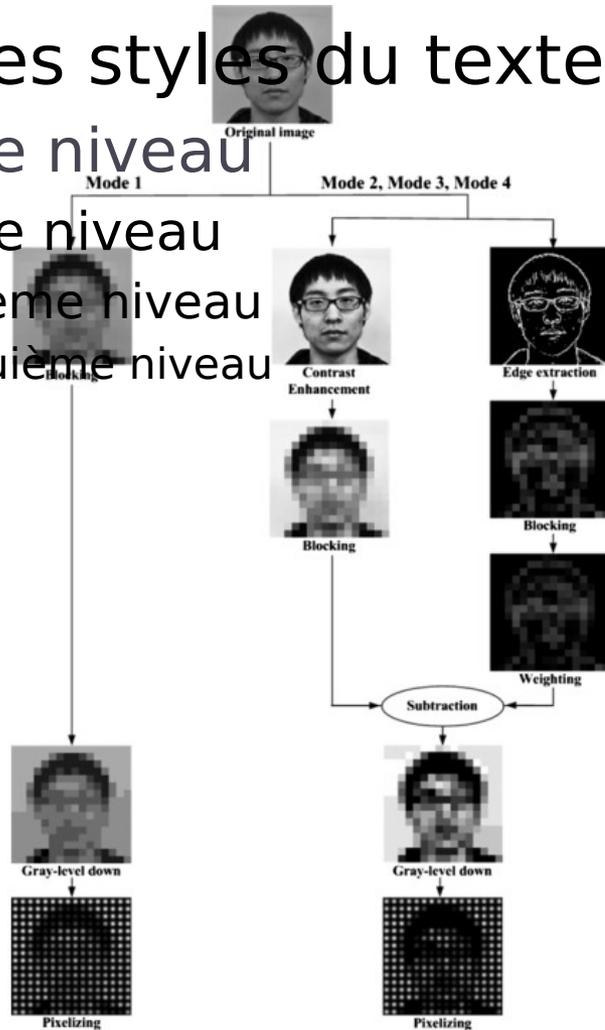


Figure 2. Flowchart for generating pixelized images. First images are subdivided into modes 1, 2, 3 and 4. For modes 2, 3, and 4, an original image is contrast enhanced and then blocked. In the meanwhile, the original image is edge extracted, blocked and weighted. After subtracting a blocked edge image from a blocked contrast-enhanced image, a pixel image was formed according to a Gaussian distribution in order to mimic prosopagnosia, whereas, for mode 1, an original image is blocked and pixelized as the others are.

Pixelized Images Recognition in Simulated Prosthetic Vision [Zhao et al, APCMBE 2008]



Fig. 1 The original object and scene images: the upper four rows are objects; the last row is the simple scenes

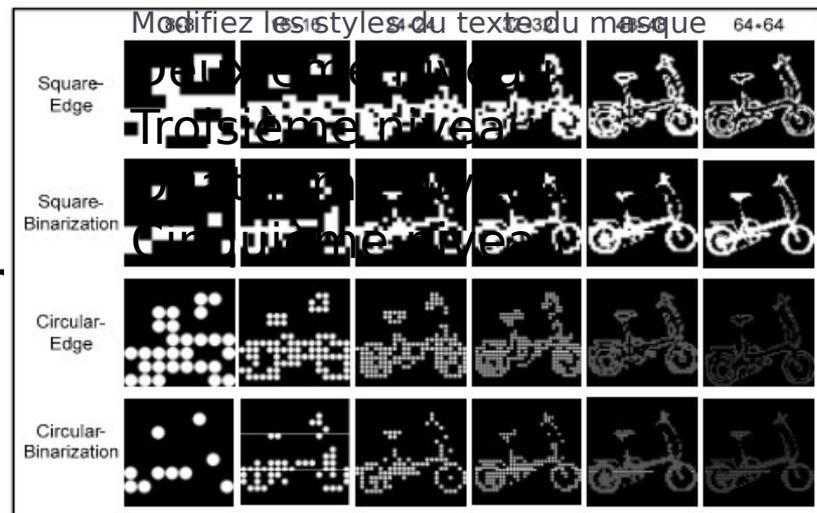


Fig. 2 Sample images used in experiment (bicycle). Each column corresponded to a given number of pixels (from 8x8 to 64x64) and each row corresponded to a given processing method and shape of pixel. The images were pixelized by white binary matrix pixels with 4.5° visual angle.

Pixelized Images Recognition in Simulated Prosthetic Vision [Zhao et al, APCMBE 2008]

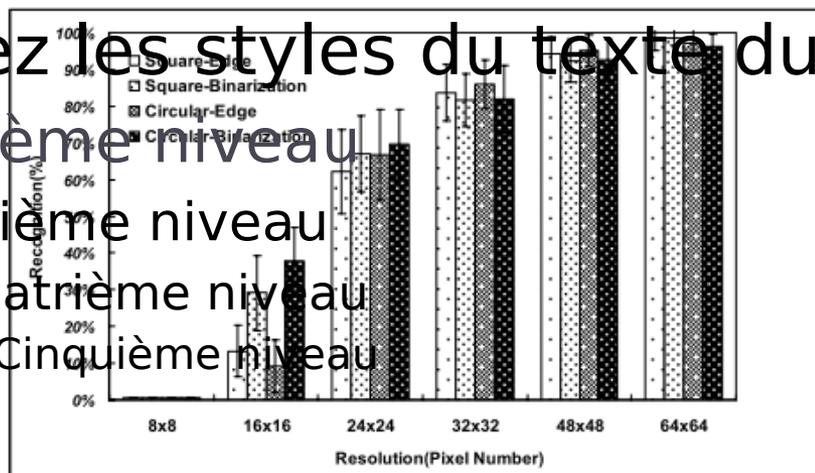


Fig. 3 Recognition of object images in four pixelized forms with different pixels array number

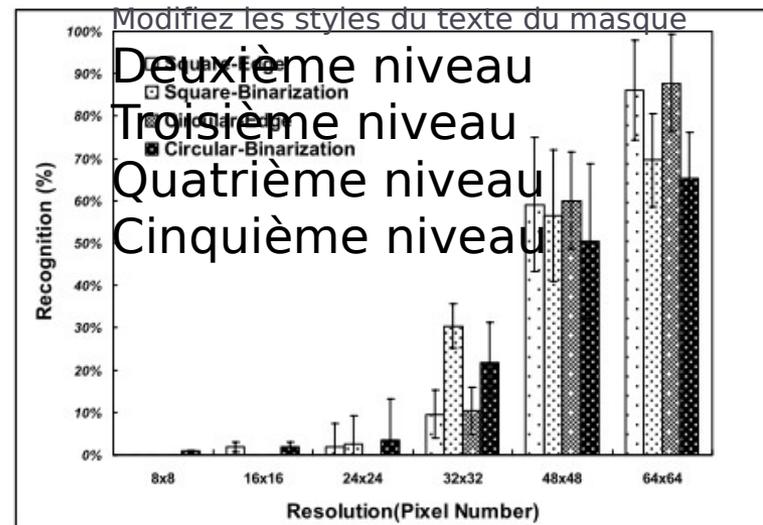


Fig. 4 Recognition of scene images in four pixelized forms with different pixels array number

Reading speed with a pixelized vision system

[Cha et al, J. Opt. Soc. Am. A 1992]

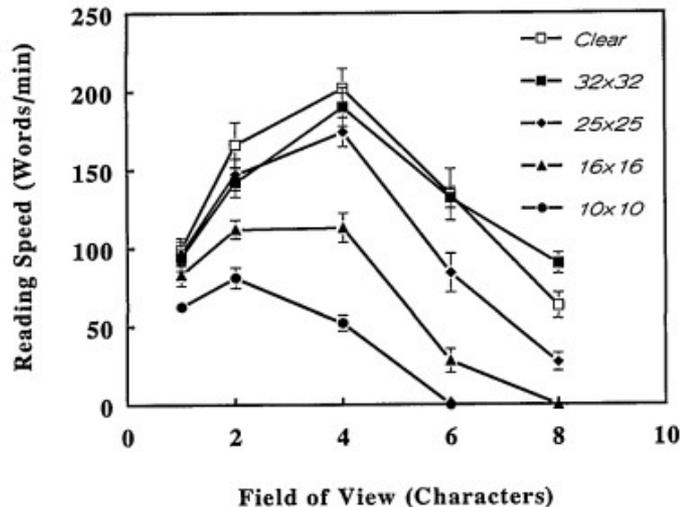


Fig. 2. Scroll-mode reading speed as a function of the number of characters visible in the field of view for different masks in which the number of pixels and their spacing varied. Fixed-field masks were used, so pixel spacing varied with pixel number, and the field of view was varied by adjusting the acceptance angle of the camera in the head scan simulator. Shown are the means \pm the standard errors for six subjects.

The results indicate that a **25 x 25 (625) array of pixels representing four letters of text projected on a foveal visual field of 1.70 is sufficient** to provide reading rates near 170 words/min with scrolled text and near 100 words/min with fixed text.

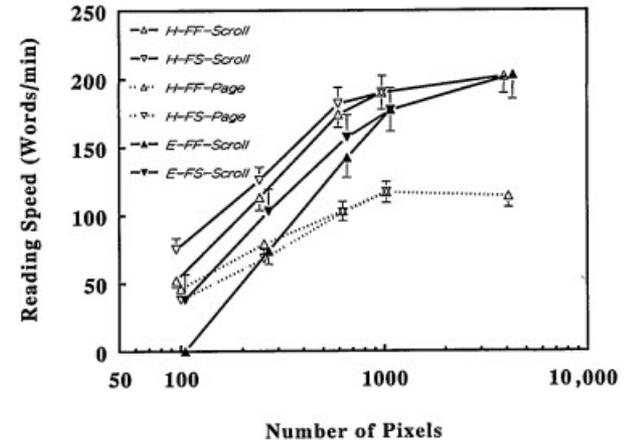


Fig. 3. Reading rates as a function of the number of pixels for different types of mask, modes of reading, and simulation systems. The data were obtained with the head scan simulator, which permitted head scanning of the text (H), and the eye tracker, which permitted eye scanning (E). Both fixed-field (FF) and fixed-spacing (FS) masks were used. With the fixed-field masks the sampling density decreased as the number of pixels decreased, but the field of view stayed constant. With the fixed-spacing masks the sampling density stayed constant, but the field of view decreased as the number of pixels decreased. The scroll-mode points are connected by solid lines, and the page-mode points are connected by dotted lines. The rightmost points are from the clear-mask condition: the number of pixels was calculated by assuming that the mask was filled completely with pixels. Plotted are the means \pm the standard errors for six subjects. Note the logarithmic axis for the number of pixels. For clarity, pairs of scroll-mode points are offset slightly, and error bars are shown on only one side of the symbols (opposite the point of the triangle).

Prévision 2008 des implants épirétiniens

Chader et al, Progress in brain research 2009

► Modifiez les styles du texte du masque

► Deuxième niveau

► Troisième niveau

□ Quatrième niveau

□ Cinquième niveau

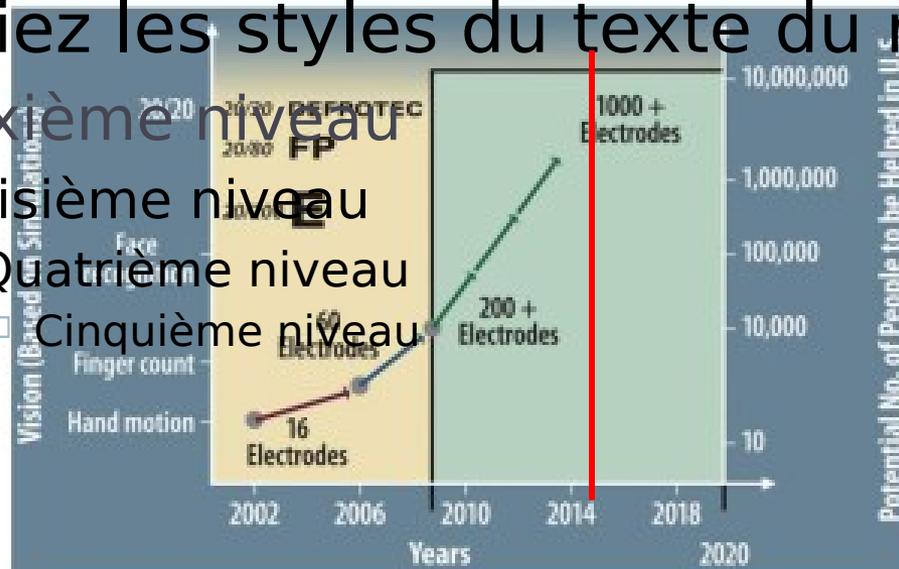


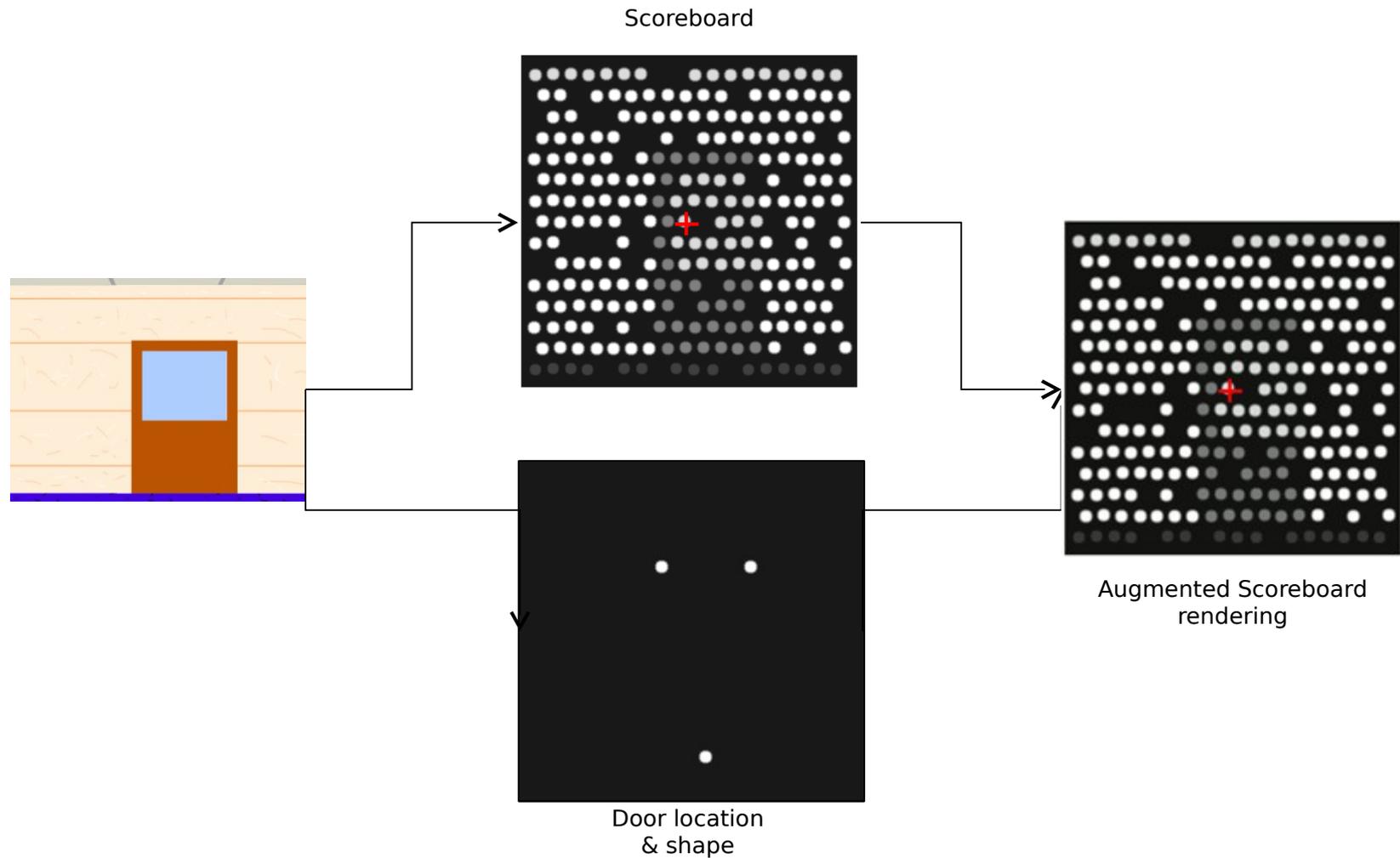
Figure 1-16 Prévision des résolutions d'implants.

Historique et prévision des résolutions d'implants épirétiniens en Janvier 2008.

En beige, les systèmes existants à l'époque, et en vert les prévisions. L'échelle de gauche indique les fonctions visuelles retrouvées. L'échelle de droite correspond au nombre de patients potentiellement concernés/équipés par ces systèmes (Source : Chader, Weiland, and Humayun 2009).

Approche fonctionnelle basée sur la tâche

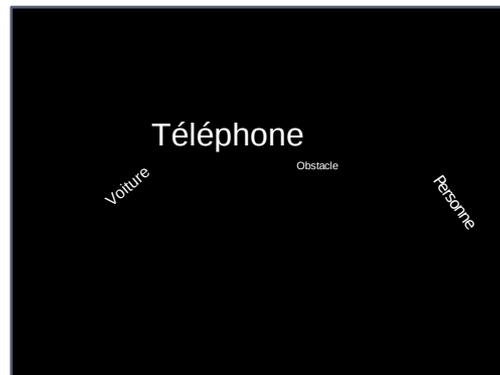
Approche fonctionnelle par localisation



Principe de la vision neuroprothétique par reconnaissance et localisation



- Score-board
- Reco et Localisation ultra-rapides



- Prise d'information permettant
 - ✓ Localisation d'objets pertinents
 - ✓ Action guidée par des objets « visuels » (restaurer des comportements « visuomoteurs »)
 - ✓ Construction d'une représentation spatiale
- Minimum de remapping (pas ou peu d'apprentissage)

Reconnaissance et localisation rapides

SpikeNet: réseau de neurones
(S. Thorpe - CerCo & SpikeNet Technology)

Autres algos

SNVision Model Builder - SNVisionM2

File Edit Image Models Processing Results Preferences View Window Help

Model Name Model

Processing Information

Pre Processing Time 12.2 ms
Total Processing Time 14.1 ms
Frame Rate 8.5 f/s
Throughput 629.2 Mpix/s

Rank	Id	Name	X	Y
1	2	Webcam	545	352
2	3	Cup	563	185
3	1	Bottle	266	178

Count: 3 AvgQuality: 1951

Ready 720 x 576 (113, 574)

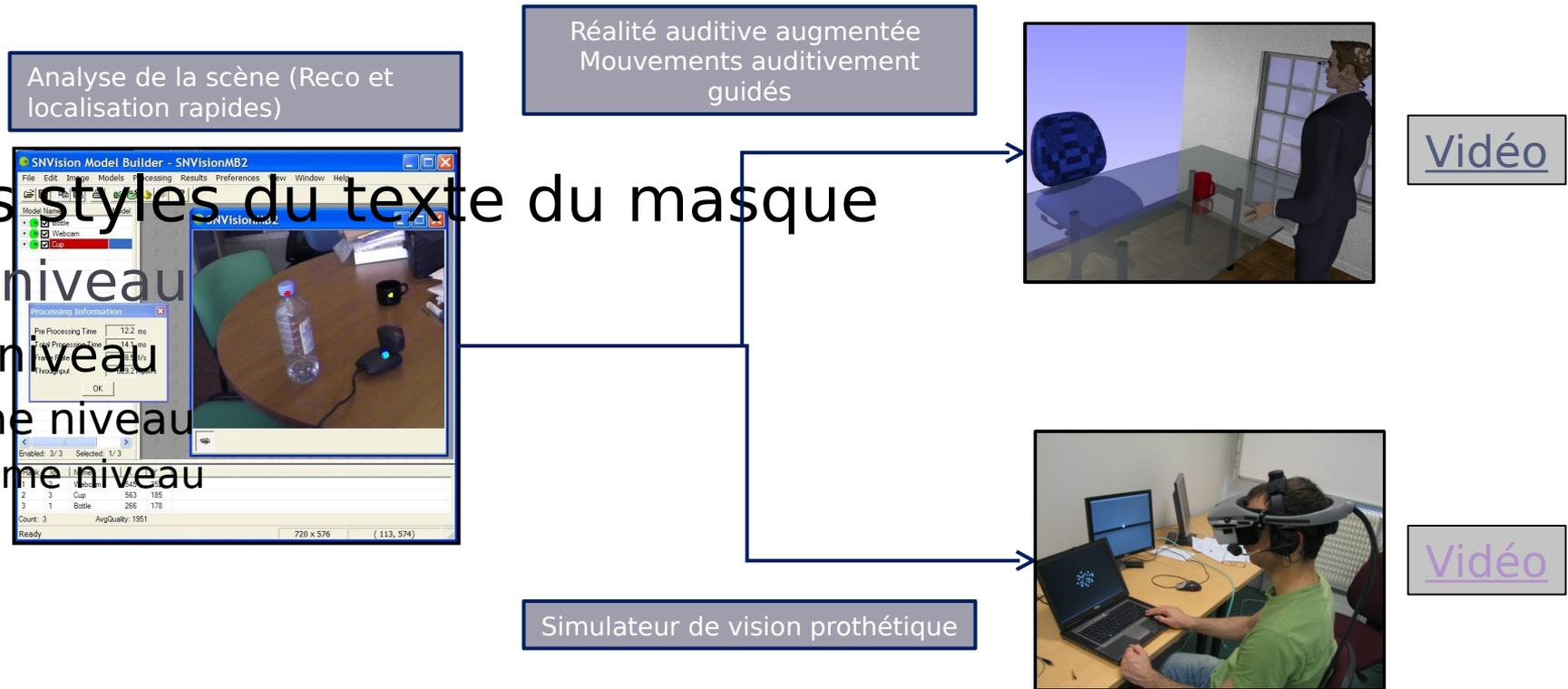
extracteur de régions d'intérêt MSER
[Matas et al. 2004]
version améliorée [Nistér & Stewénus 2008]

Reco visages [Viola & Jones 2001]
Planar Classification in Urban Scenes
(Bauda et al 2015)
Etc.

Svt disponibles dans librairie OpenCV
Récupérables en ligne
Collaborations IRIT



Problématique de la suppléance visuelle par reconnaissance et localisation



SPV par localisation d'objets



Modèle d'interface neurale:

- Nb et position
- Taille et forme
- Contraste
- Clignotement
- Couleur



Évaluation des fonctions

« visuomotrices restaurées »

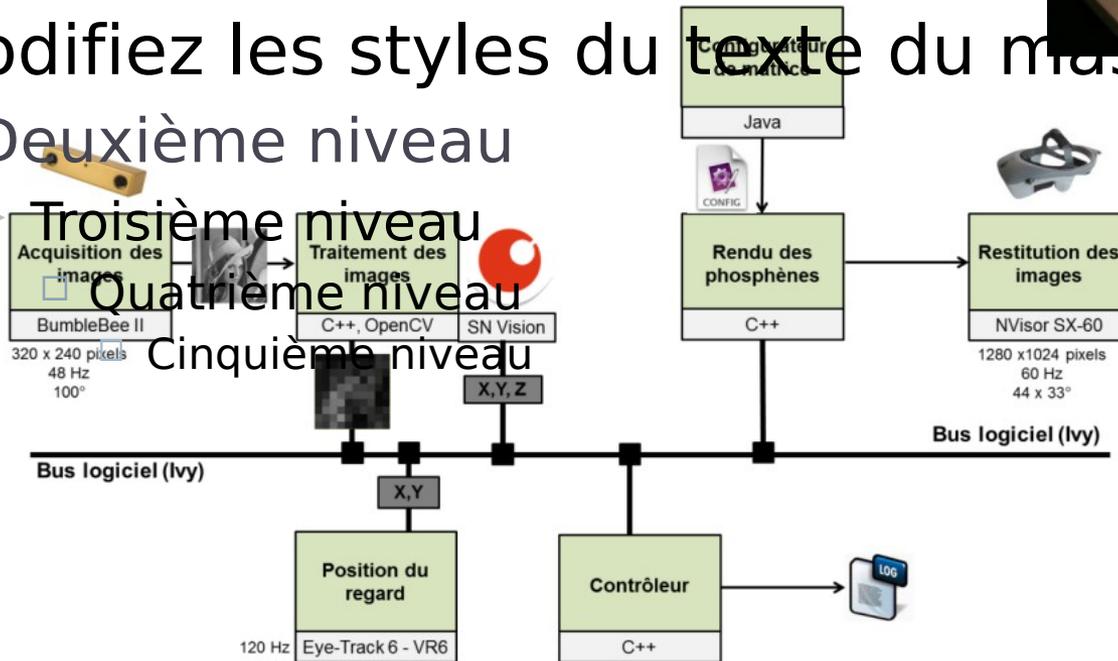
- Localisation d'objets
- Saisie d'objets
- Navigation

Architecture du SPV

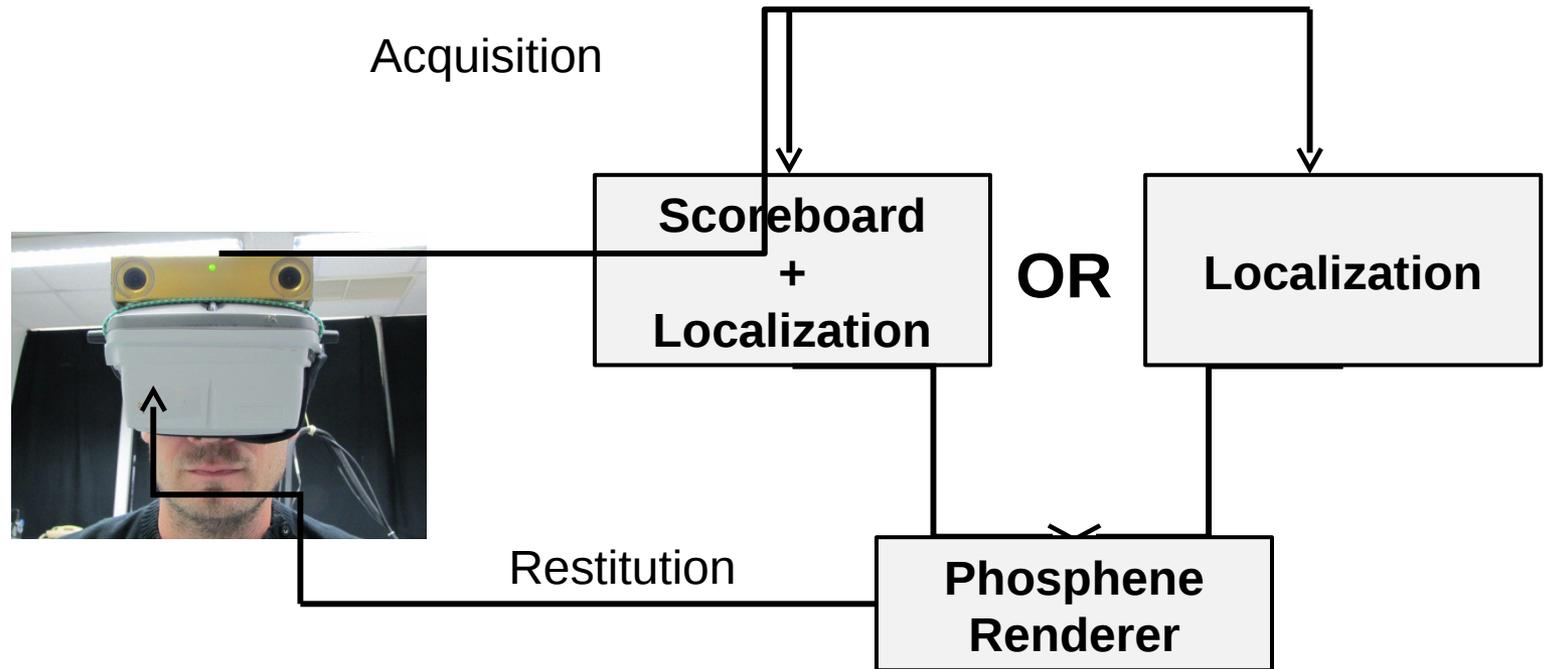


- ▶ Modifiez les styles du texte du masque
- ▶ Deuxième niveau

- ▶ Troisième niveau
- ▶ Quatrième niveau
- ▶ Cinquième niveau



SPV: Différentes configurations



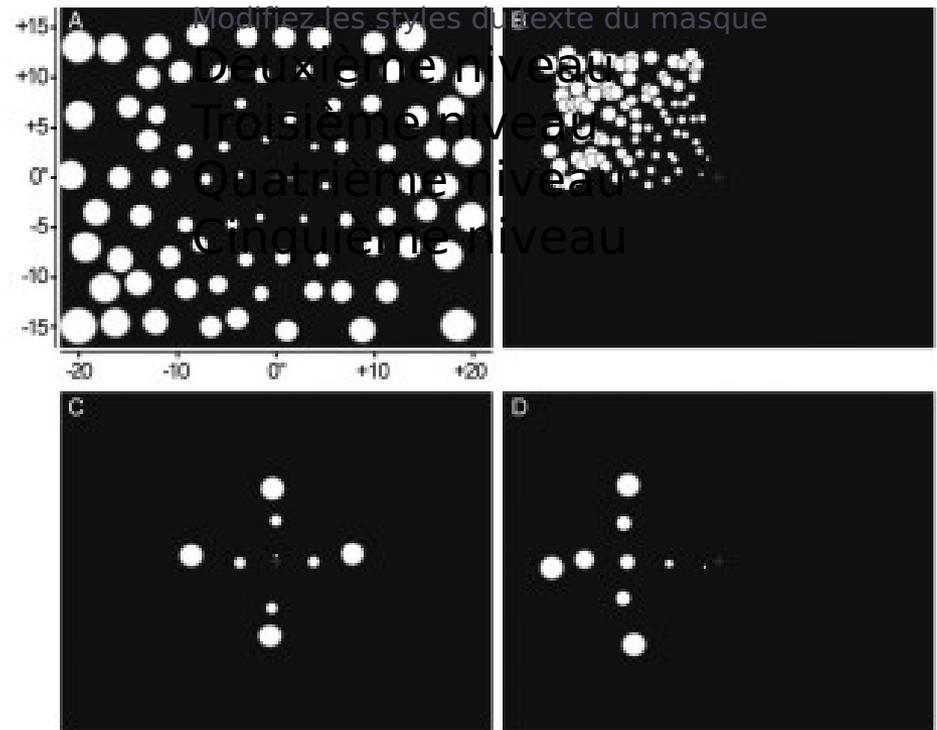
- ☑ **Head Mounted Display**
- ☑ **Camera stereo**
- ☑ **Composants logiciels (C++, Java)**

+ **Motion capture system**



Tâche de saisie d'objet

- ▶ Capture par caméra binoculaire de 100°
- ▶ Détection par SpikeNet
- ▶ Atteindre objet sur la table
- ▶ 7 objets répartis aléatoirement parmi 11 emplacements
- ▶ 14 sujets
- ▶ 30 saisies par objet
- ▶ 4 configurations d'interfaces neurales



Macé, M. J.-M., Guivarch, V., Denis, G., & Jouffrais, C. (2015). Simulated Prosthetic Vision: The Benefits of Computer-Based Object Recognition and Localization. *Artificial Organs*, (6), 12.

Expérience de saisie d'objets

- ▶ Modifiez les styles du texte du masque
 - ▶ Deuxième niveau
 - ▶ Troisième niveau
 - Quatrième niveau
 - Cinquième niveau



Résultats saisie d'objets

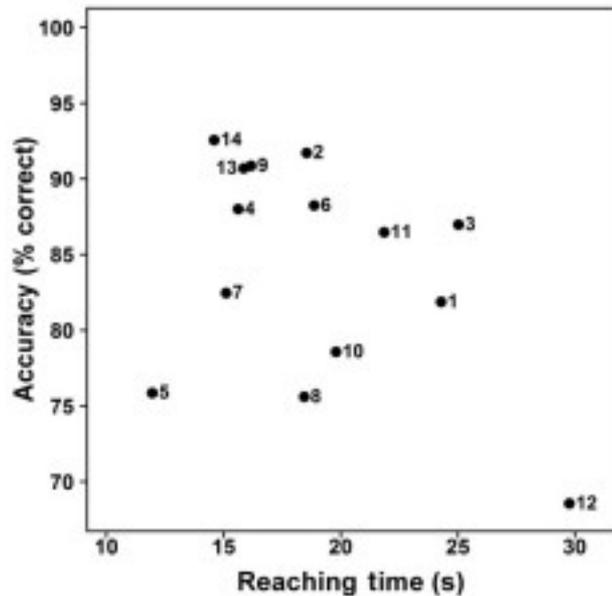


FIG. 3. Average time to reach an object (in seconds) as a function of accuracy (% correct) for all subjects in all conditions together. In the lower right-hand corner, subject S12 clearly appears as an outlier. S13 and S14, the two non-naïve subjects, have a performance comparable with S2, S4, and S6.

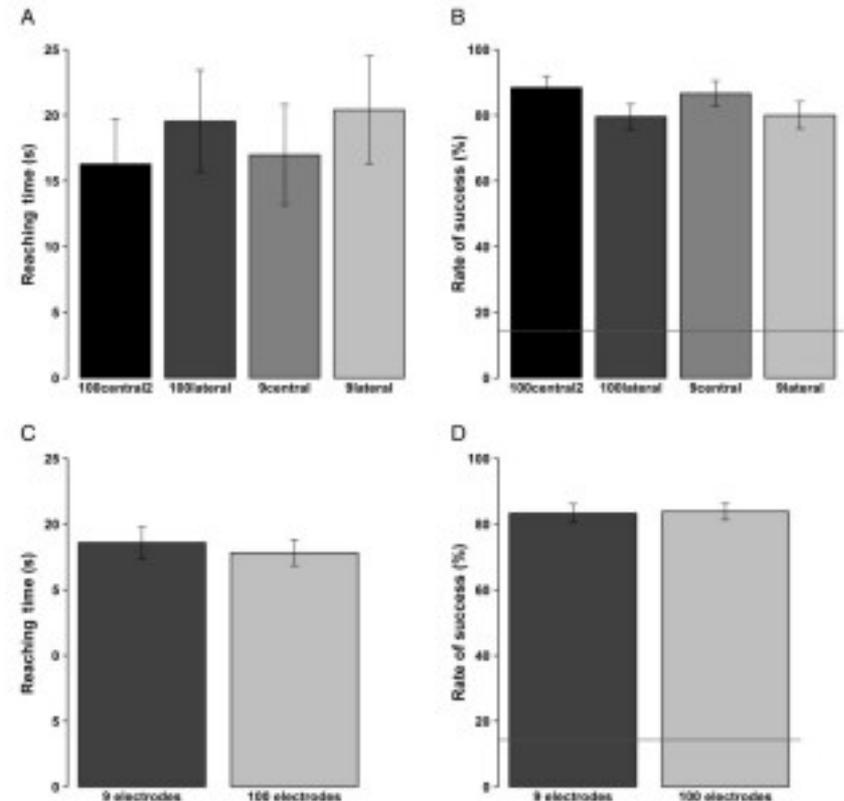


FIG. 4. (A) Median reaching time (in seconds) and (B) mean reaching accuracy across phosphene layouts. (C) Median reaching time and (D) mean reaching accuracy for small and large arrays of electrodes (respectively 9 and 100 electrodes). The horizontal line indicates chance level in the task (=14.3 %).

Localisation de visages

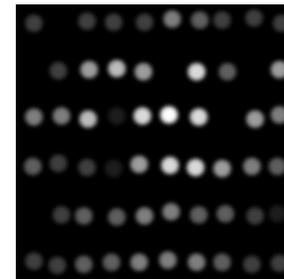
Vue caméra (100°)



Scoreboard



Vue simulateur

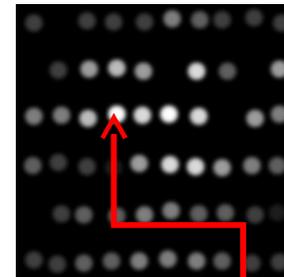


Argus2
6x10

Scoreboard

+

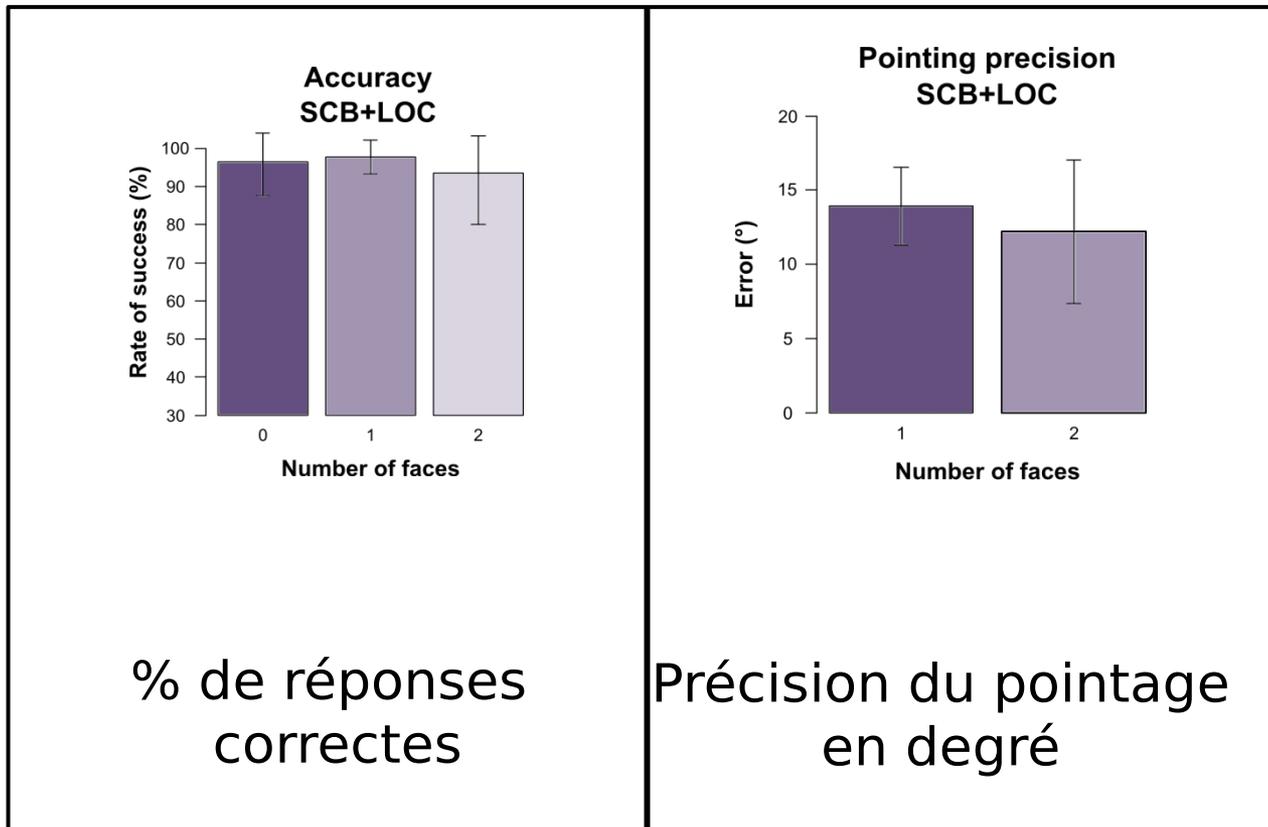
Localization



Phosphore blanc clignotant

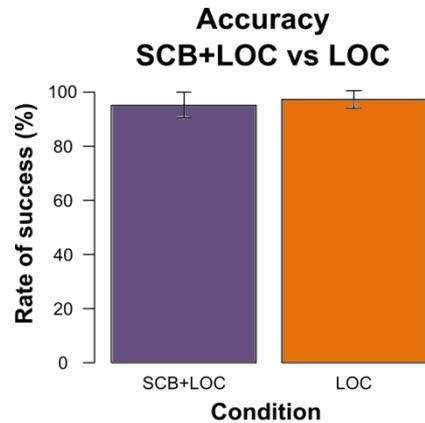


Performance (Scoreboard + Localisation)

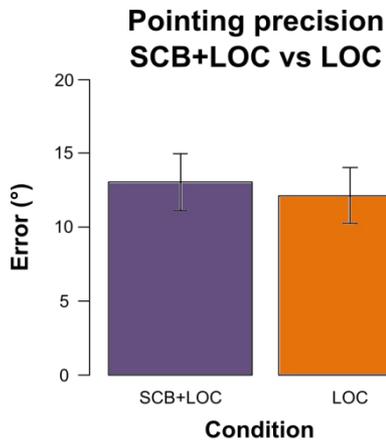


Denis, G., Jouffrais, C., Vergnieux, V., & Macé, M. J.-M. (2013). Human faces detection and localization with simulated prosthetic vision. In *Proceedings of the 2013 Conference on Human Factors in Computing Systems*

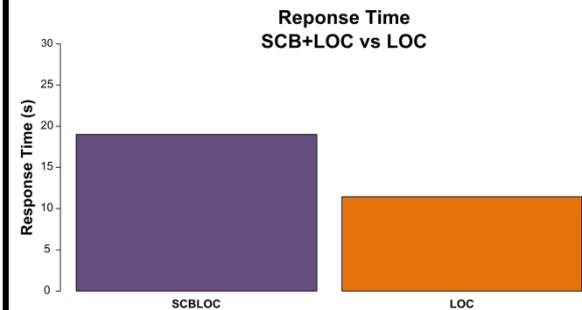
Importance du contexte



% de réponses correctes



Précision du pointage en degré



Temps pour effectuer la tâche

Localisation de textes

- ▶ Modifiez les styles du texte du masque

- ▶ Deuxième niveau

- ▶ Troisième niveau

- Quatrième niveau

- Cinquième niveau

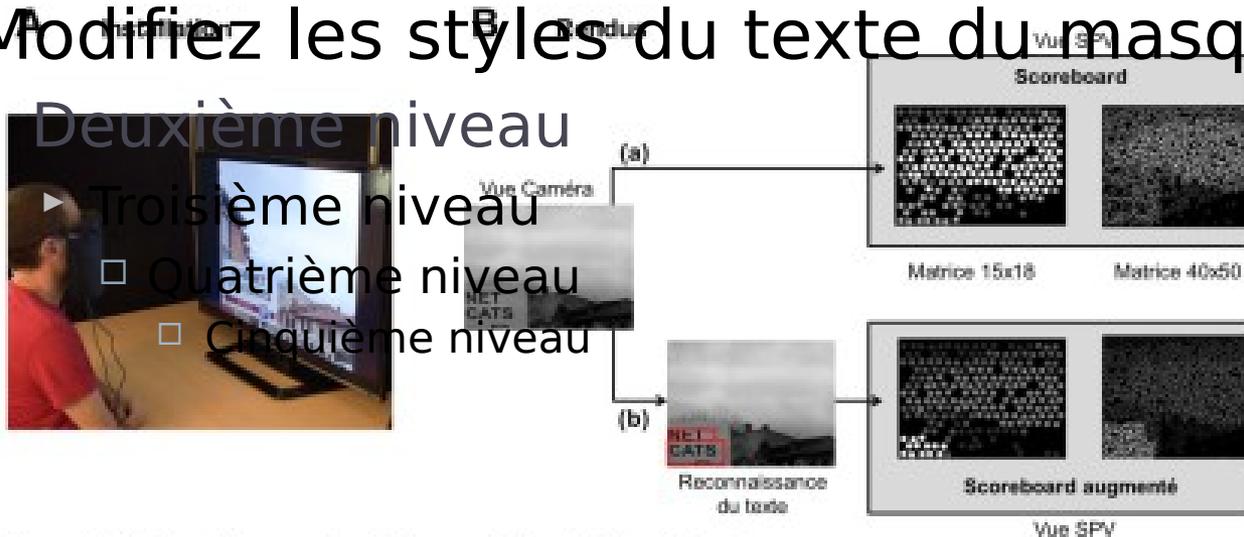


Figure 6-1 Disposition pour l'expérience de localisation de texte.

A - Vue d'ensemble du dispositif pour l'expérience de localisation de texte. Le sujet était assis à 57 cm d'un téléviseur et devait localiser des blocs de texte en vision prothétique simulée. B - Les deux rendus utilisés dans cette expérience : (a) rendu basé sur l'approche scoreboard, l'image est simplement réduite à la résolution de la matrice ; (b) rendu basé sur l'approche scoreboard augmenté, les blocs de texte reconnus apparaissent distinctement avec des phosphènes blancs.

Localisation de textes

- ▶ Modifiez les styles du texte du masque

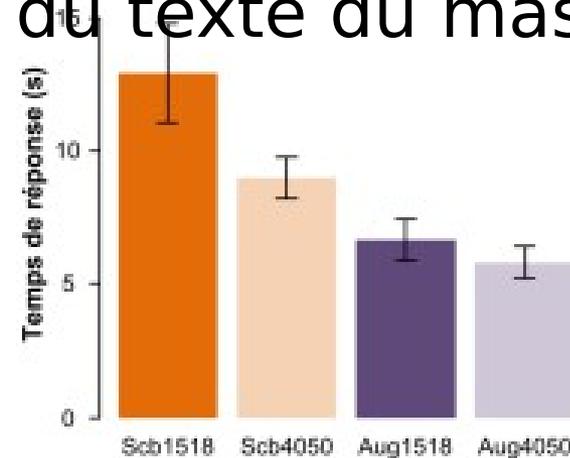


Figure 6-4 Précision et temps de réponse.
À gauche, la précision des sujets par condition. La ligne en pointillés rouges correspond au niveau chance (20% : 5 réponses possibles). À droite, le temps de réponse des sujets pour chacune des quatre conditions.

Conclusions localisation d'objets / visages

- ▶ Tâche impossible avec un Argus II
- ▶ Tâche impossible avec un Argus II simulé
- ▶ Tâche facile si on rajoute information de localisation
- ▶ Tâche réalisée plus rapidement en localisation seule: la vision scoreboard rajoute du bruit et ralentit la prise de décision
- ▶ On pourrait imaginer un **switch** permettant à l'utilisateur de contrôler le passage d'un rendu à un autre



Mobility and orientation

Mobility performance with a pixelized vision system

[Cha et al, Vis Res 1992]

Modifiez les styles du texte du m

Deuxième niveau

Troisième niveau

Quatrième niveau

Cinquième niveau

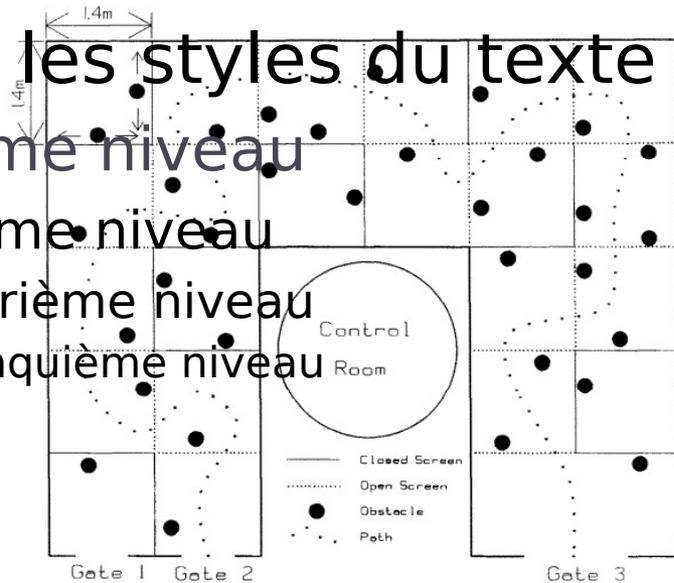


FIGURE 1. Indoor mobility course. The room was divided into 1.4 x 1.4 m square blocks with cloth screens. Dotted and solid lines indicate open and closed screens that create a particular path through the maze. Solid circles indicate suspended paper cylindrical obstacles, 5 cm in dia and 1.8 m in length, which could be moved to different positions in front of the screens as indicated by the arrows in the upper left corner of the figure. The course started at either gate 1 or gate 2 and ended at gate 3. The heavy dotted line indicates a pathway through the maze.

LEARNING
Modifiez les styles du texte du masque

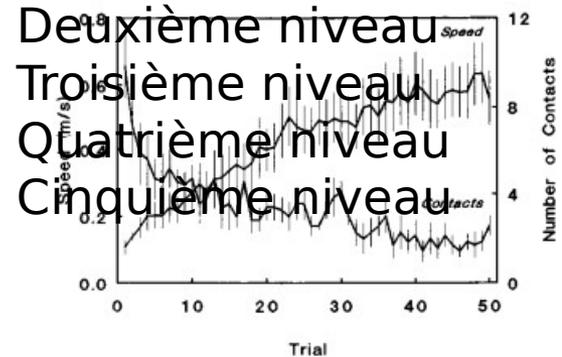


FIGURE 2. Learning curves. 7 subjects walked through the maze with a 32 x 32 pixel mask and a visual field of 13°. Walking speed and number of body contacts were measured for each trial. The solid lines indicate means of the 7 subjects' performance and vertical bars indicate standard errors.

$$32 \times 32 = 1024 \text{ pixels}$$

$$\text{FOV} = 13^\circ$$

Prétests et hypothèses

- ▶ Mobilité (Wayfinding?) avec SCB
 - ▶ Résolution supérieure à 1000 pixels
- ▶ Mobilité (Wayfinding?) avec SPV de localisation
 - ▶ pas de compréhension de la scène, désorientation, tâche impossible
- ▶ Hypothèses
 - ▶ Crowding de l'information visuelle sur interface de basse résolution
 - ▶ Compréhension globale de la structure de la scène (passages / obstacles) nécessaire
 - ▶ Landmarks nécessaire pour orientation □ peuvent être déduits de la structure

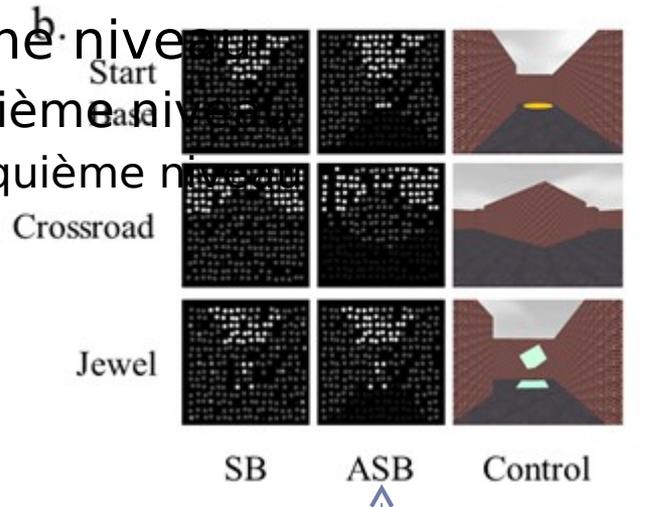


Wayfinding with Simulated Prosthetic Vision: Performance comparison with regular and structure-enhanced renderings

Modifiez les styles du texte du masque
 Deuxième niveau



Troisième niveau
 Quatrième niveau
 Cinquième niveau

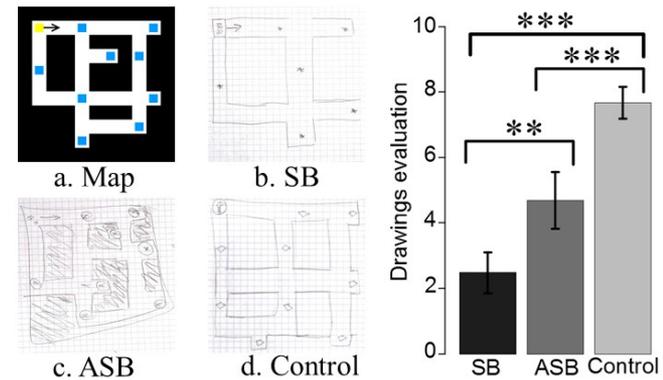


e.g. Planar Classification in Urban Scenes (Bauda et al 2015)

- a. Environment maps: start base and jewels are indicated in yellow and blue respectively. The arrow represents the subject's orientation at the beginning of the task.
- b. Samples of the three rendering conditions used in this study



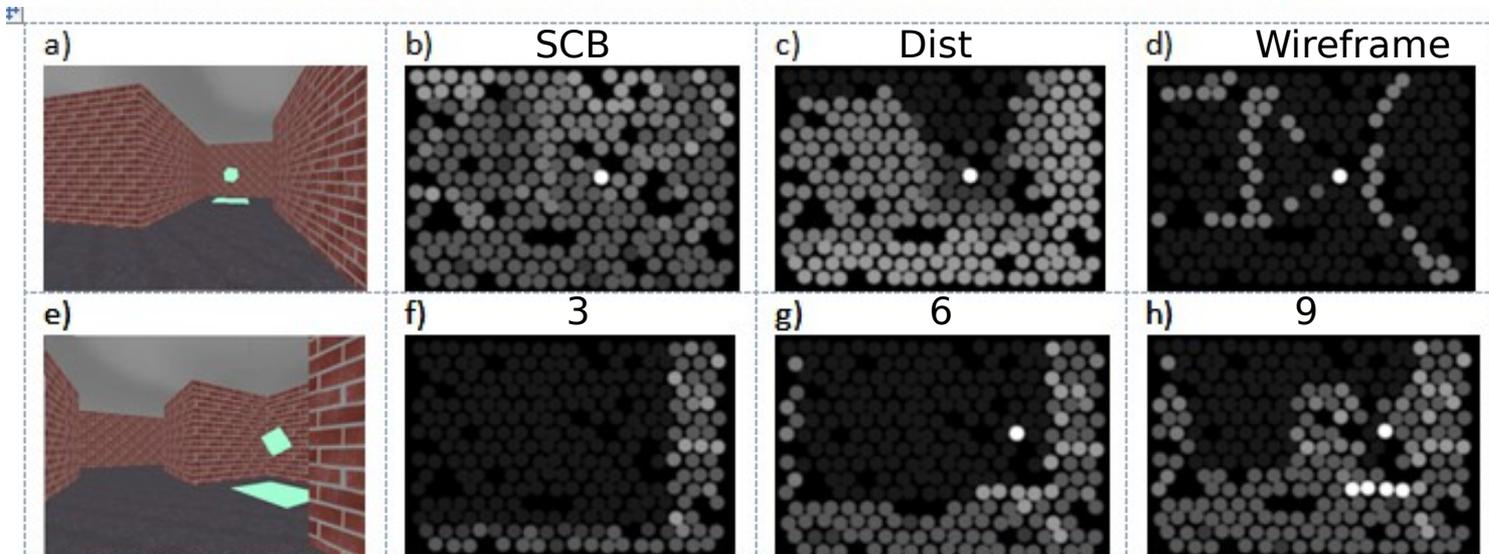
Performance index per condition. Mean number of secured jewels in each condition is written in white within the columns



Left: Map and drawing examples (from different subjects) a. Map of environment #1; b. Drawing after SB condition; c. after ASB condition; d. after Control condition. Right: Mean drawing scores per condition (n=12 subjects).

See less to see more: concealing visual information helps to navigate with Simulated Prosthetic Vision

Vergniew et al. Submitted



Perf index with Virtual Vision

- ▶ Modifiez les styles du texte du masque

- ▶ Deuxième niveau

- ▶ Troisième niveau

□ Quatrième niveau

□ Cinquième niveau



Figure 3: Averaged Performance Indices for the different Virtual Vision Conditions. VV-3 condition presents significant difference with others conditions. Error-bars are 95% confidence intervals.

Perf Index with SPV

- ▶ Modifiez les styles du texte du masque

- ▶ Deuxième niveau

- ▶ Troisième niveau

- ▶ Quatrième niveau

- ▶ Cinquième niveau



Figure 1: Averaged Performance Indices for the different Simulated Prosthetic Vision Conditions. SPV-Control and SPV-3 conditions have the same significant difference with SPV-Distance, SPV-6 and SPV-Wireframe conditions. Error-bars are 95% confidence intervals.

Map acurateness

- ▶ Modifiez les styles de texte du masque

- ▶ Deuxième niveau

- ▶ Troisième niveau

- Quatrième niveau

- Cinquième niveau

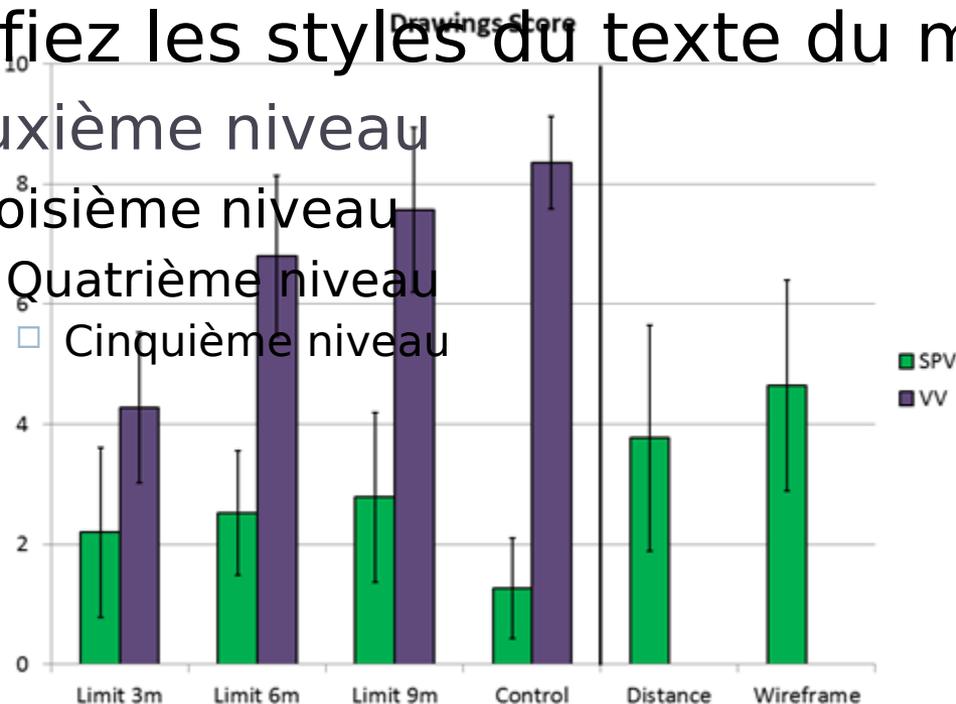


Figure 8: Means of map scores given by four independent judges. Simulated Prosthetic Vision conditions are in green, the other conditions are in purple. Important differences inter-subjects gave great variance in our data. Error-bars are 95% confidence intervals.

Cognitive load

- ▶ Modifiez les styles du texte du masque
 - ▶ Deuxième niveau
 - ▶ Troisième niveau
 - Quatrième niveau
 - Cinquième niveau

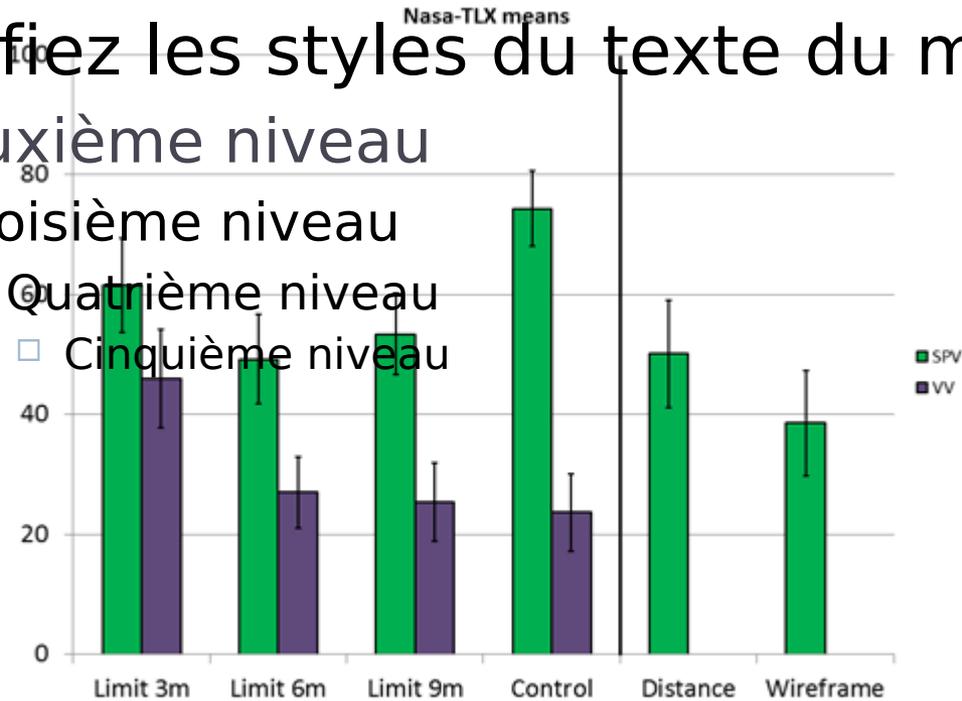


Figure 7 : Averaged NASA-TLX Indices for each condition. Simulated Prosthetic Vision renderings are in green, the Virtual Vision conditions are in purple. We note a symmetric evolution between Nasa-TLX means and PI means for limited conditions. Error-bars are 95% confidence intervals.

“Gaming effect”

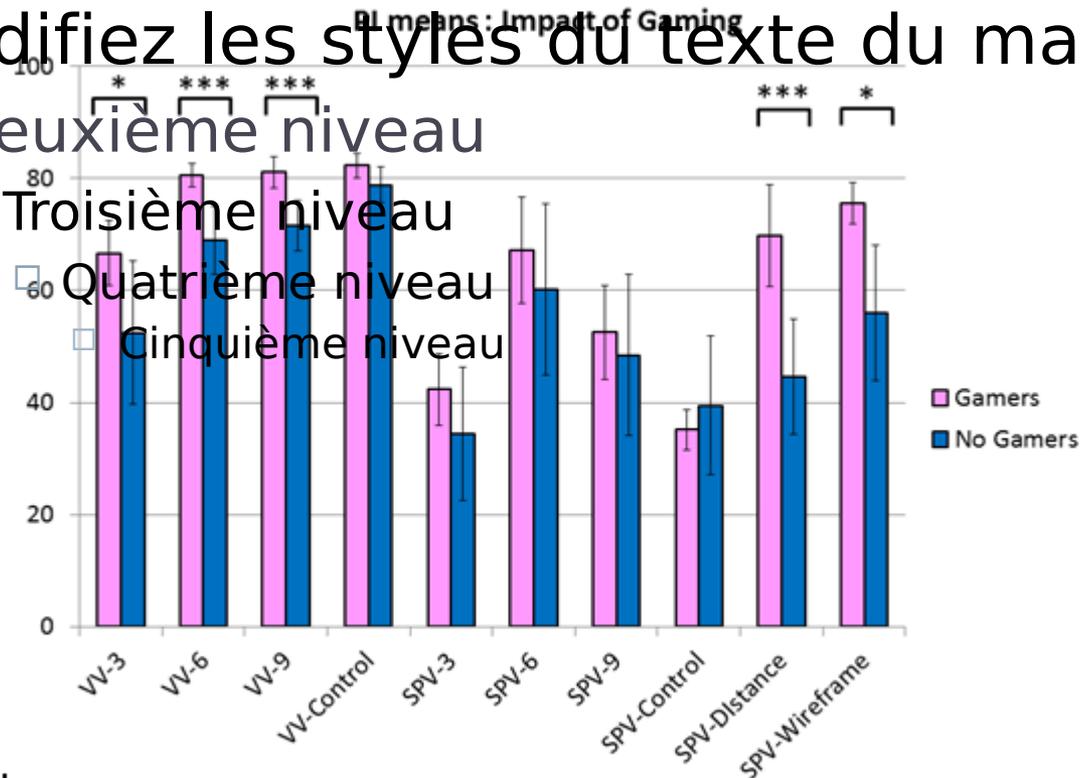
- ▶ Modifiez les styles du texte du masque

- ▶ Deuxième niveau

- ▶ Troisième niveau

- ▶ Quatrième niveau

- ▶ Cinquième niveau



I

Figure 5: Difference of PI means between the gamers and the no gamers. This graph shows that gamers manage to use the augmented SPV renderings with more efficacy than the no gamers. Error-bars are 95% confidence intervals

Conclusions / Discussion

- ▶ L'approche holistique (scoreboard) est-elle la plus fonctionnelle ?
- ▶ Possible d'induire des comportements orientés et des représentations mentales de l'espace avec:
 - ▶ peu de phosphènes
 - ▶ des algo de vision embarquée spécifiques à la tâche en cours
- ▶ Plusieurs algorithmes sur étagère sont utilisables
- ▶ Interfaces neurales actuelles, à basse résolution (Argus 6*10; UTAH 10*10) peuvent être (sont?) utilisables avec vision embarquée
- ▶ Différents algorithmes embarqués spécifiques à la tâche en cours
- ▶ Contrôle de l'implant avec une télécommande?



Remote control of the visual neuroprosthesis

- ▶ Modifiez les styles de texte du masque
- ▶ Deuxième niveau
 - ▶ Troisième niveau
 - Quatrième niveau
 - Cinquième niveau



Figure Disc-1 Rendus visuels et actions disponibles dans le logiciel servant à l'interaction avec la neuroprothèse.

Plusieurs modes sont accessibles pour la navigation et la localisation d'objets d'intérêt. Une liste d'action est disponible pour chacun des modes (Source des simulations : Denis, Macé, & Jouffrais, 2014; Lui, Browne, Kleeman, Drummond, & Li, 2012; McCarthy & Barnes, 2012; McCarthy, Feng, & Barnes, 2013).

Action	Interaction		Feedback
	Tactile	Orale	
Sélectionner un rendu		« mode navigation »	Retour audio des noms de menus et sous-menus + Retour visuel (modification du rendu)
Zoomer / Dézoomer		« action zoomer » / « action dézoomer »	Retour audio sur le niveau de zoom + Retour visuel (modification de la scène)
Sélectionner un bloc de texte		centrer le bloc dans le champ de vision + « action sélectionner »	Retour audio sur le contenu du texte

Figure Disc-2 Exemples d'interactions possibles avec la neuroprothèse visuelle.

Chaque action est exécutable par une interaction avec la surface tactile du dispositif portable ou activable par commande vocale.

Collaborateurs

▶ IRIT:

- ▶ Marc Macé
- ▶ Florian Dramas, Grégoire Denis, Victor Vergni
- ▶ Corinne Maillhes, Jean-Yves Tourneret



▶ CerCo et SpikeNet Technology

- ▶ Simon Thorpe, Rudy Guyonneau



<http://www.irit.fr/~Christophe.Jouffrais>
Christophe.Jouffrais@free.fr

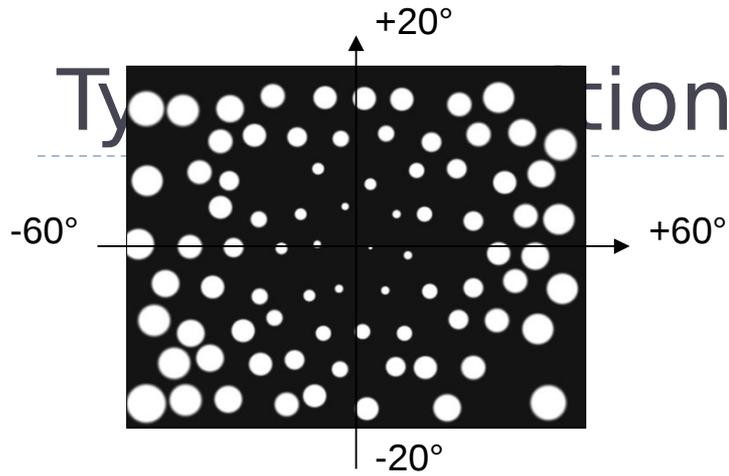
CHERCHONS
**POUR
VOIR**



Plateforme de recherche
technologique au service
des déficients visuels

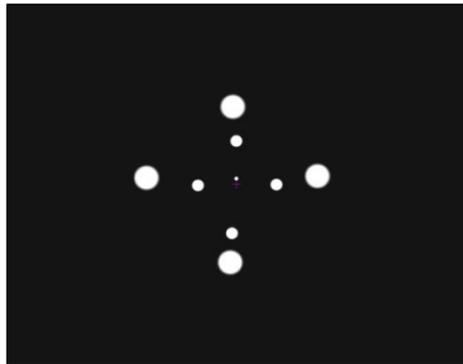


Type de configuration des interfaces

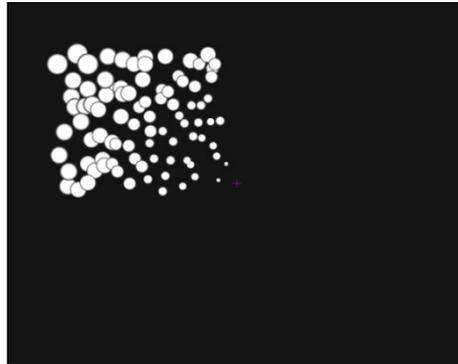


90 central

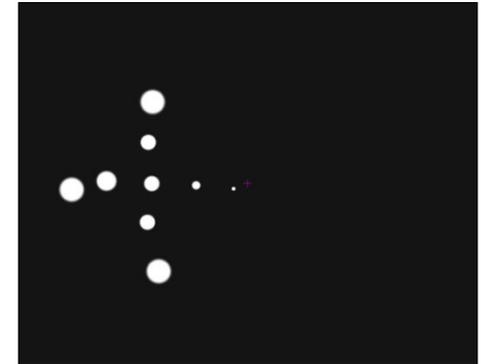
- Bruit sur la position
- 10% d'électrodes non fonctionnelles
- Magnification corticale
- 4 configurations d'électrodes



9 central



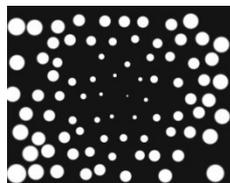
90 latéral



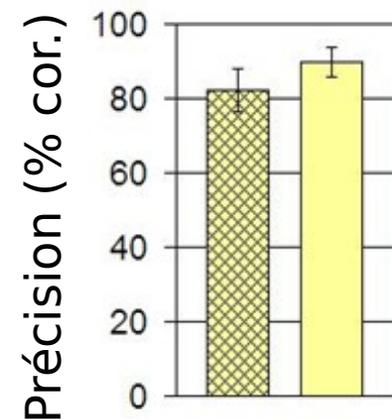
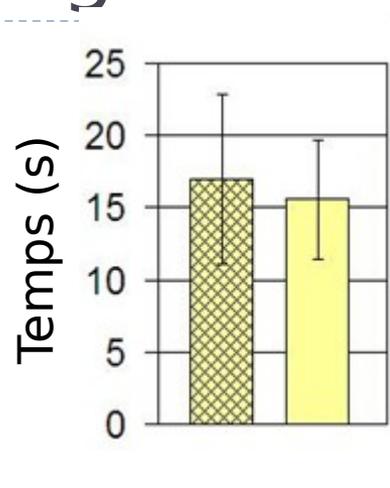
9 latéral



Effet d'apprentissage



90 central



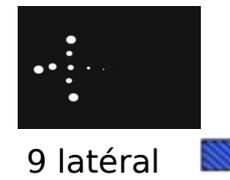
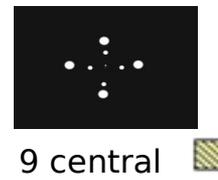
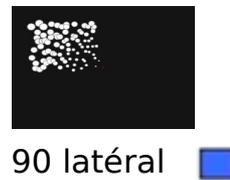
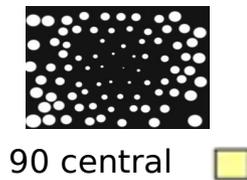
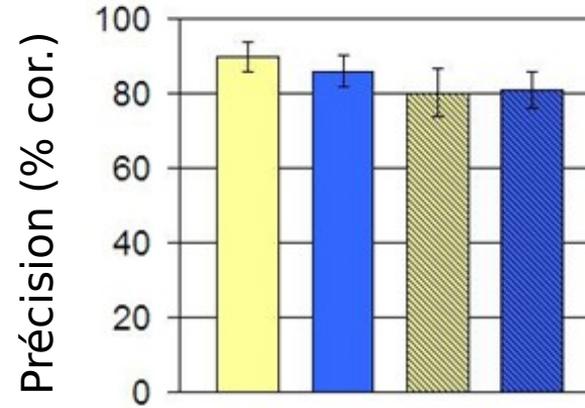
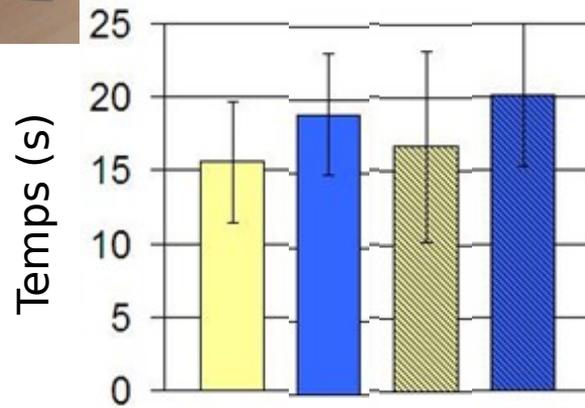
2 heures d'apprentissage

□ Pas d'amélioration signif. de performance





- Durée moyenne : $\approx 17s$
- Précision moyenne: 84% correct

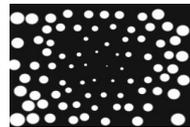
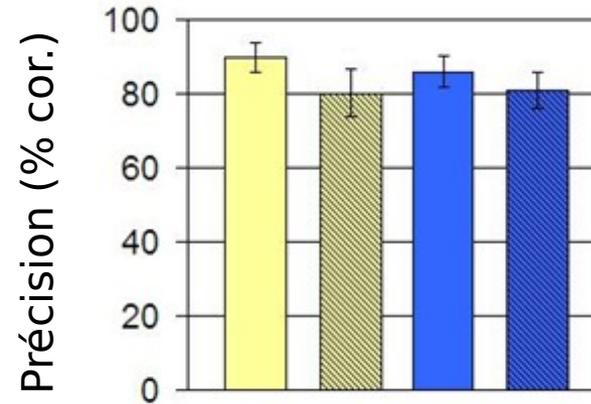
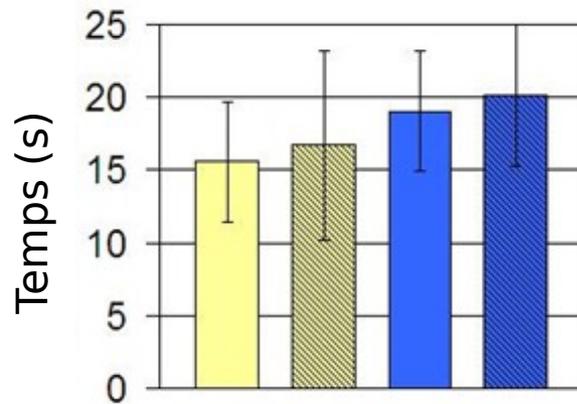


Résultats



- Durée moyenne : $\approx 17s$
- Précision moyenne: 84% correct

□ 9 phosphènes sont suffisants pour effectuer la tâche



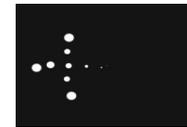
90 central



90 latéral



9 central

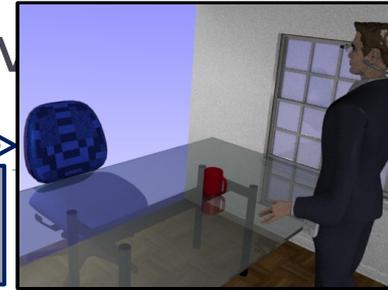


9 latéral

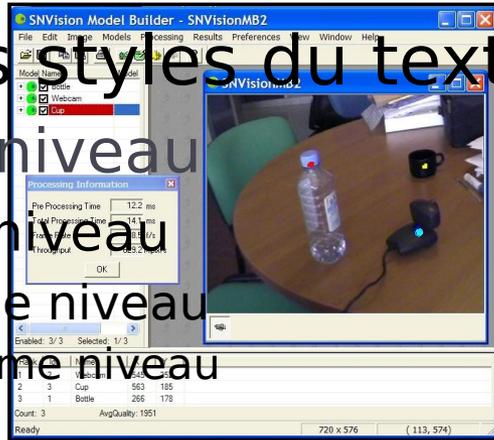
Problématique de la suppléance visuelle reconnaissance et localisation

Analyse de la scène (Reco et localisation rapides)

Réalité auditive augmentée
Mouvements auditivement guidés



Vidéo



Les styles du texte du masque

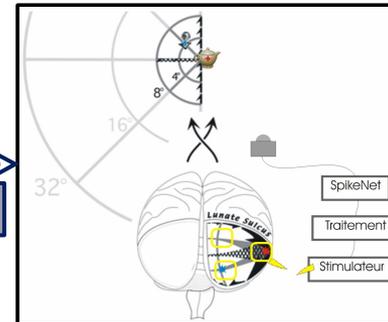
le niveau
le niveau
le niveau
le niveau
le niveau

Simulateur de vision prothétique



Vidéo

Interface Cerveau-Machine



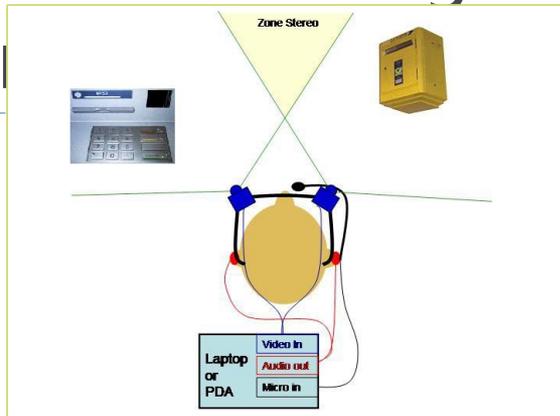
NAVIG: Navigation assistée par Vision

al

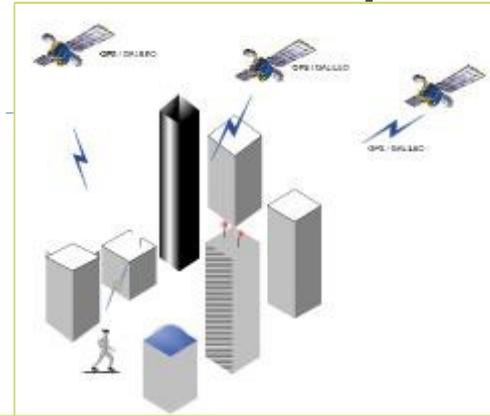
ISS



<http://navig.irit.fr>



- Localisation des cibles
 - par rapport à la tête
 - en 10 ms / cible
 - précision 20 cm
- Détection d'obstacles (flux)
- Navigation vers des objets



- Géolocalisation du piéton (5m)
- Géolocalisation des cibles
- Navigation vers des destinations
- Centrale inertielle



Vidéo

- Navigation améliorée (int/ext, précision ~20 cm)
- Localisation et saisie d'objets

- Recherches en cours:
- SIG adapté
 - Positionnement
 - Guidage (interaction) qui favorise les représentations « configuration »



- Modifiez les styles d'écriture
- Deuxième niveau
- Troisième niveau
- Quatrième niveau
- Cinquième niveau



7 non-voyants

5, 10, 20 et 50 euros

Utilisabilité jugée excellente

Usage peut être étendu (CD, DVD, emballages aliments, etc.)

Concept d'un dispositif avec plusieurs fonctions apprécié

(Parlouar et al, ASSETS 2009)

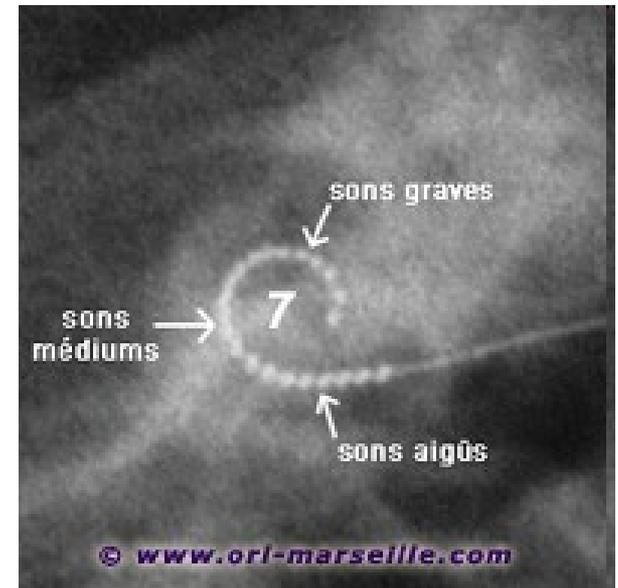


Futur des neuroprothèses visuelles

- Parallèle avec les implants cochléaires
- Les prothèses motrices
- Quel avenir pour les neuroprothèses visuelles ?

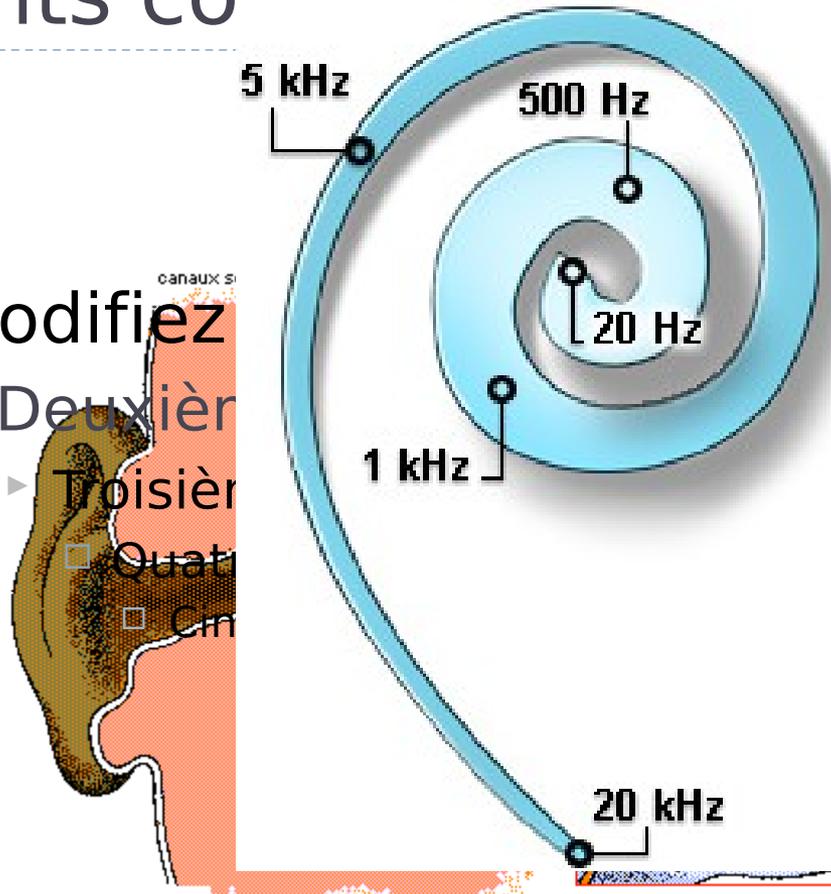


Implants cochléaires

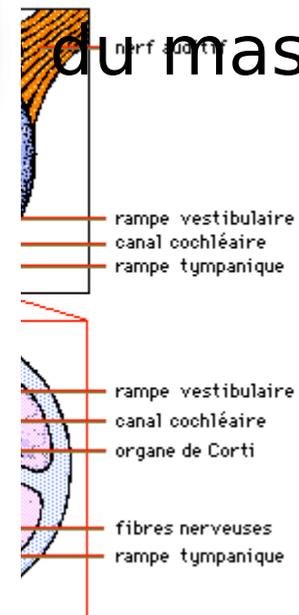


Implants cochléaires

- ▶ Modifiez
- ▶ Deuxième
- ▶ Troisième
- Quatrième
- Cinquième



du masque



Implants cochléaires

pour modifier les styles du texte

me niveau

me niveau

trième niveau

nquième niveau



50 000 implants en 2000
 190 000 en 2009
 250 000 aujourd'hui
 30 000 € euros par implantation
 3 heures d'opération par oreille

Cliquez pour modifier les styles du texte du masque

Deuxième niveau

Troisième niveau

Quatrième niveau

Cinquième niveau



Complications fréquentes, mais
 peu sévères
 3 à 6% de pannes nécessitant
 une ré-opération

Implants cochléaires

- ▶ Après 6 ans d'expérience de l'implant :
 - ▶ Possibilité de suivre une conversation en liste ouverte
 - ▶ sans l'aide de la lecture labiale pour près de 80% des enfants.
- ▶ L'apprentissage du langage est identique, mais décalé dans le temps par rapport à l'apprentissage de l'enfant normo-entendant.
- ▶ Enquête sur la qualité de vie toujours positives, même pour les sujets âgés



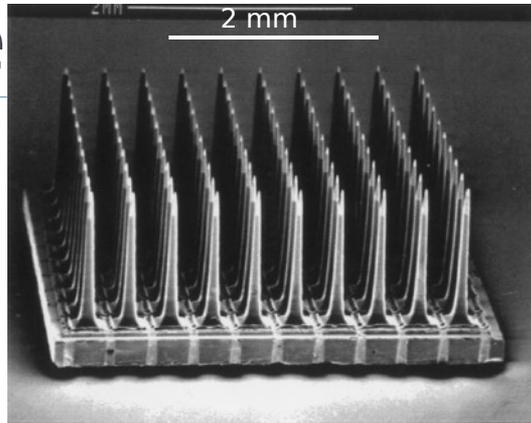
Prothèses motrices



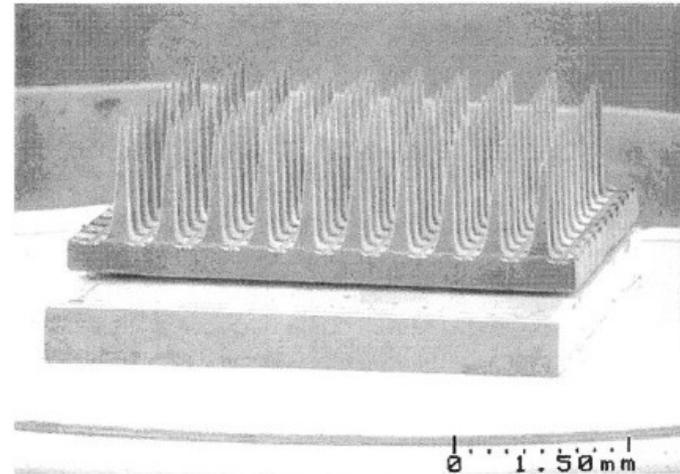
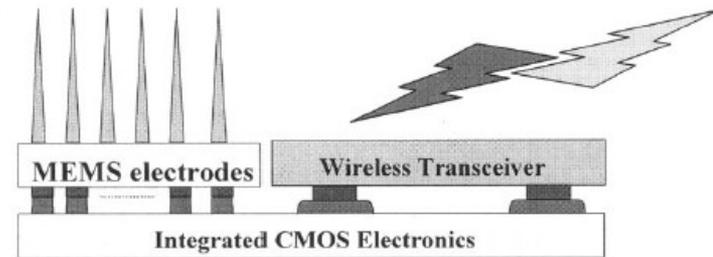
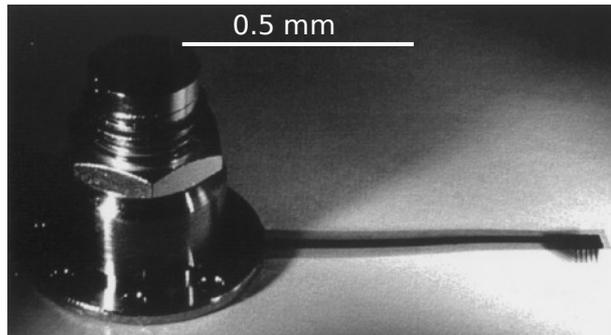
« Luke's arm »
Dean Kanen



Le Contrôleur



B



A - Micrographe par balayage électronique de la matrice de 100 microélectrodes UEA 'Utah Electrode Array' et B - Photo du connecteur percutané (Normann, 1999). C - Implant sans fil (Mojarradi, 2003)

Activités nécessitant de l'aide

Faire des courses	59,7 %
Payer les comptes	40,6 %
Effectuer les transactions bancaires	39,8 %
Faire les travaux ménagers	38,6 %
Lire	36,4 %
Prendre de l'information	34,7 %
Rédiger la correspondance	30,7 %
Ménager les repas	31,3 %
Faire la lessive	22,2 %
Se déplacer dans le quartier	19,9 %
Faire fonctionner les appareils ménagers	18,5 %
Prendre des médicaments	18,2 %
Choisir ses vêtements	17 %
Utiliser le transport en commun	16,2 %
Participer à des activités sociales	14,2 %
Faire sa toilette	11,9 %
Utiliser un ordinateur	11,4 %
Prendre soin des enfants	2,6 %
Autre	2,8 %

Incidences des besoins non satisfaits	Tous
Je ne peux pas faire ce que je veux	43,7 %
Je me sens isolé	37 %
Mon revenu a diminué	18,5 %
Je ne me sens pas en sécurité	17,8 %
Je ne peux pas travailler	15,6 %
Je ne peux pas prendre soin de moi-même adéquatement	11,9 %
Je ne peux pas prendre soin de ma famille adéquatement	5,2 %
Autre	20 %

INCA 2005; 352 adultes interrogés

Impact des nouvelles technologies

- Inclusion

- Accès au soutien et aux services
- Monde scolaire, professionnel et vie communautaire
- Participation aux politiques publiques

- Culture et Loisirs

- Musée, Expositions
- Jeux

- Communication (Lecture et écriture)

- Perception, action et cognition spatiales

- Prise d'information (Reconnaissance d'objets)
- Orientation et Mobilité

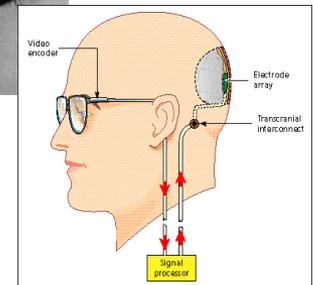
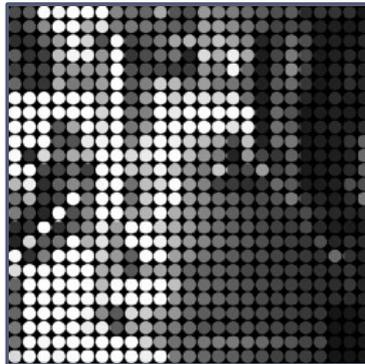
Activités

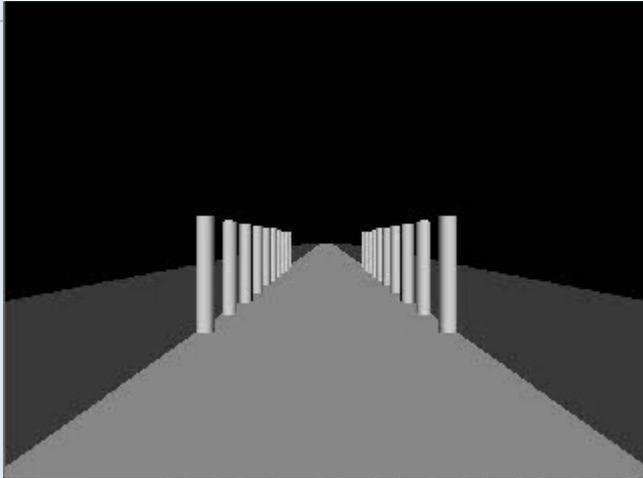


Problématique de la suppléance visuelle



- Score-board
- Interaction non visuelle (substitution sensorielle)
- Interaction neurale





substitution sen

Restitution somesthésique

Vision par substitution

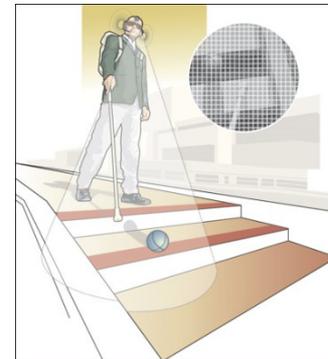
- Tactile Vision Substitution System - TVSS
- Tongue Display Unit - TDU



- Restitution auditive
 - Prosthesis for Substitution of Vision by Audition - PSVA
 - The Voice

□ Perception de formes simples

- Problèmes identifiés:
 - Interprétation et apprentissage
 - Gêne, inconfort
 - 3D en 2D
 - Résolution du récepteur de substitution



Electrical Stimulation of Visual Cortex Offers Hope for a Functional Prosthesis

Dobelle et al, Science 1974.

Artificial Vision for the Blind: « Electrical Stimulation of Visual Cortex Offers Hope for a Functional Prosthesis »

- ▶ 64 platinum disk electrodes (1mm² in area), arranged in an 8 by 8 hexagonal array
- ▶ in the subdural space
- ▶ The patient who had been blind for 28 years reported colorless, flickering phosphenes "about the size of a coin at arm's length" from all responsive electrodes.

Modifiez les styles du texte du masque

Deuxième niveau
Troisième niveau
Quatrième niveau
Cinquième niveau



Driving

Interfaces corticales de surface

- ▶ Brindley & Lewin
1968 / Dobelle 1974
- ▶ Dobelle 2000: recap
sur 20 ans

Patient implanté pendant 20 ans
64 électrodes
Phosphènes N&B
Tâches de reco simples
Interactions non linéaires

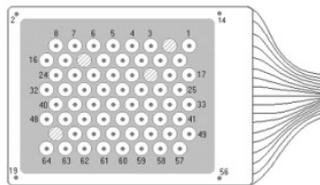
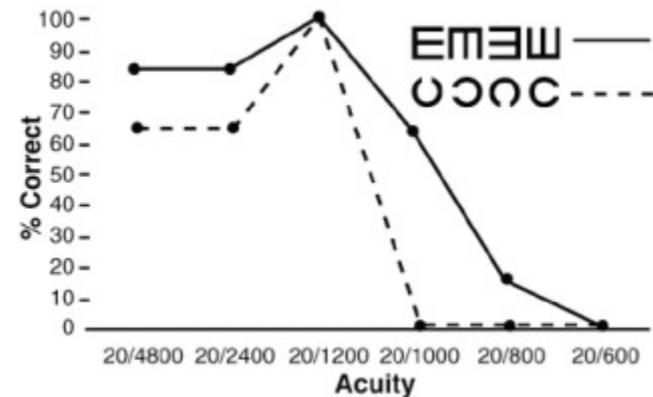


Figure 5. Electrode layout, as seen on the mesial surface of the right occipital lobe (looking through the electrode). Electrode #19 in the lower left hand corner of the array corresponds to the electrode in the lower right hand corner of the X-ray shown in Figure 4.



Interface sur le nerf optique [Veraart et al 2003]

les styles du texte
 me niveau
 me niveau
 rième niveau
 aisième niveau

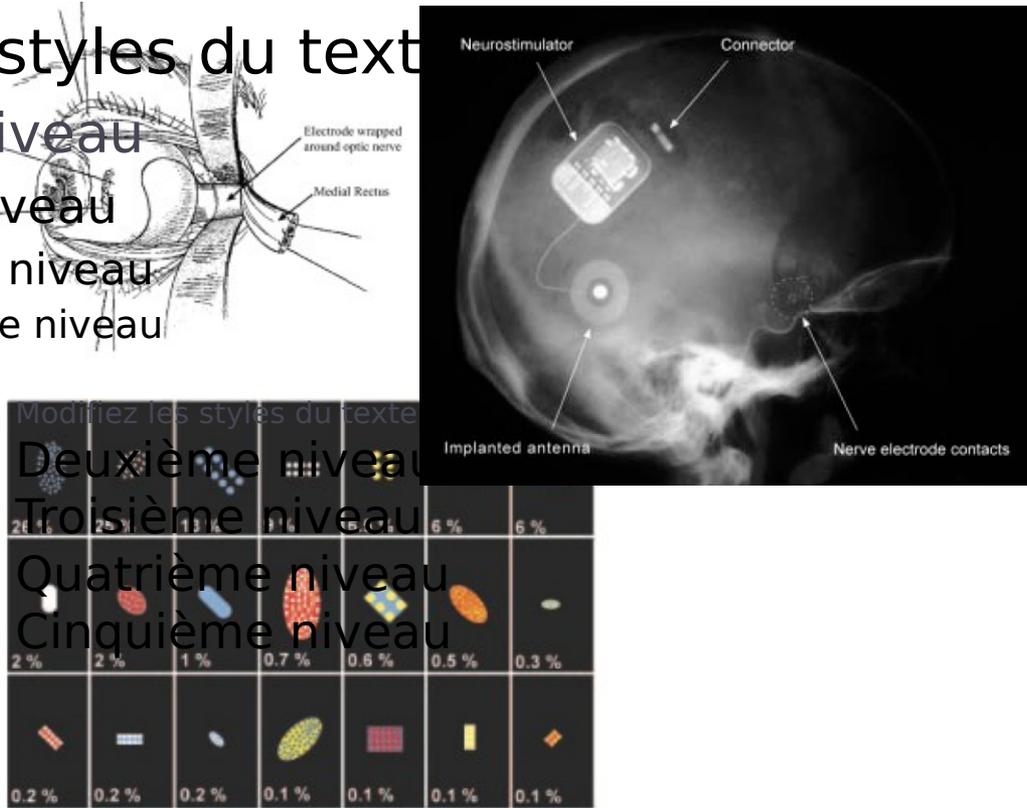


FIG. 4. Examples of phosphene description provided by the volunteer. Each of these artist representations of the volunteer's perception is attached a number indicating its frequency of occurrence among the different kinds of phosphene description. Arbitrary scale. Phosphene mean area usually ranged from about 1 to almost 10 square degrees. The overall visual field background—represented here in black—sometimes appeared locally colored behind the phosphene foreground as indicated.

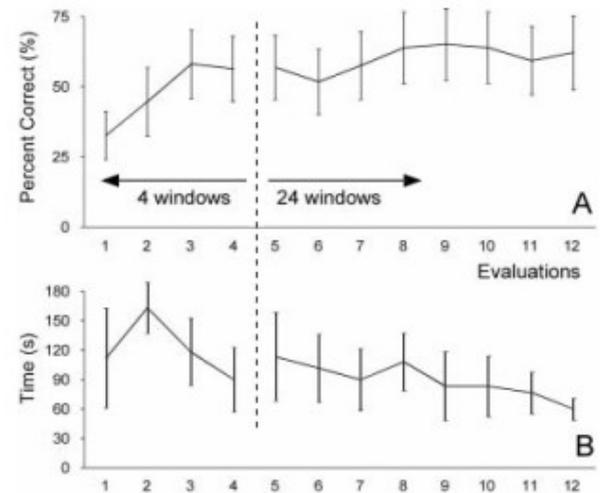
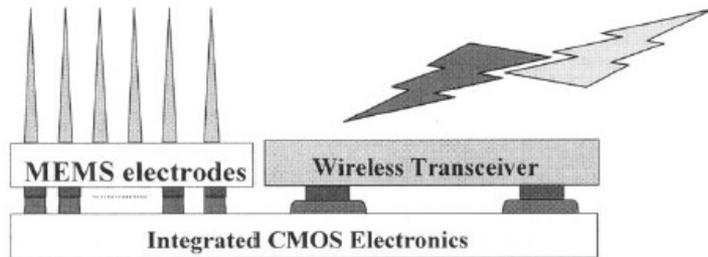
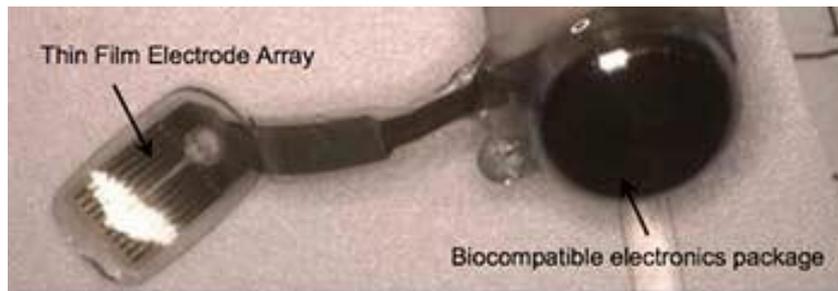


FIG. 5. Volunteer's performance in pattern recognition. (A) Percentage of weighted score (mean \pm 1SD) in recognition of the 25 patterns randomly projected during every evaluation, ordinate, as a function of evaluation number, abscissa; the first four evaluations were performed with four "windows" within the volunteer's visual field, while for the last eight evaluations 24 windows were used. (B) Processing time in seconds (mean \pm 1SD) as a function of evaluation number, under the same experimental conditions.

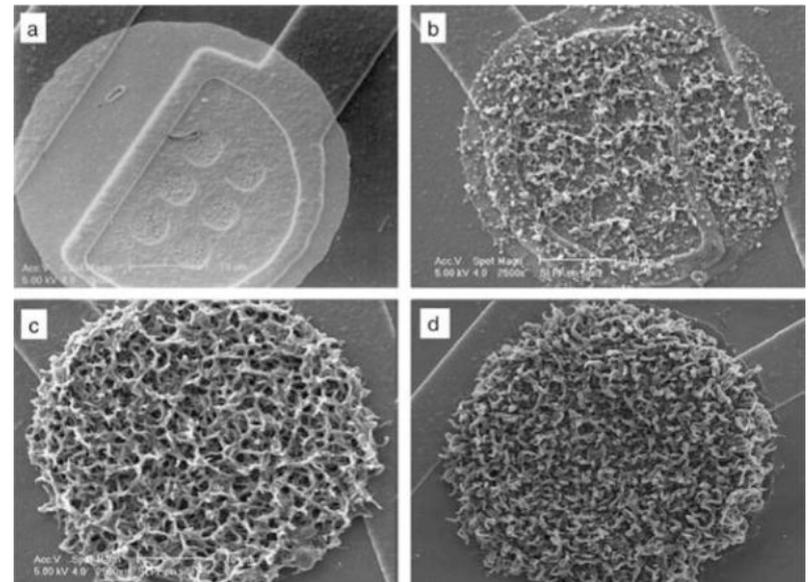
Implants



Implant sans fil (Mojarradi, 2003)



ARGUS III - 256 électrodes (Livermore Lab)



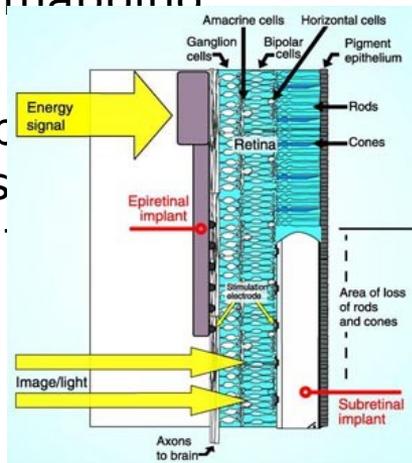
Nanostructuration d'électrodes
Projet AO3 Nanostim

Interfaces rétiniennes

(Norman et al Vis Res 1999)

Advantages of a retinal approach

- ▶ Use existing physiological optics
- ▶ Less invasive and less severe consequences of infection
- ▶ Closer to photoreceptors: easier spatial mapping
- ▶ More of process stimulation



Drawbacks of a retinal approach

- Stimulation of ganglion cell (GC) bodies or optic nerve fibers?
- Hard to ensure chronic GC/electrode apposition.
- Encapsulation of the array will reduce GC/electrode apposition.
- Multiple visual representations by ganglion cells. As ganglion cells encode spatial, chromatic, intensity and temporal information, it is not clear what features will be evoked by current injections via a retinal electrode array.
- High mechanical constraints.
- Limited to outer retinal pathologies.
- Patterned stimulation ?

Approche rétinienne ou corticale?

(Norman et al Vis Res 1999)

Advantages of a cortical approach

- ▶ The skull provides a more rugged housing for the implant.
- ▶ Penetrating arrays have been and can be simply inserted into visual cortex.
- ▶ Stable stimulation site.
- ▶ Successful long term animal studies.
- ▶ Provides a solution to pathologies not only of the outer retina, but to the entire retina, optic nerve, and thalamus.

Problems with a cortical approach

Non-conformal retinotopic mapping.

Multiple visual representations in cortex (color, intensity, orientation, ocular dominance, and other spatial features).

Convolutated cortical anatomy : implantation difficult or impossible.

Surgical complications (Meningeal infections).

Societal perceptions of brain implant.

Patterned stimulation may not produce patterned perceptions.



Tâche de Snellen

Modifiez les styles du texte du masque

Deuxième niveau

Troisième niveau

Quatrième niveau

Cinquième niveau

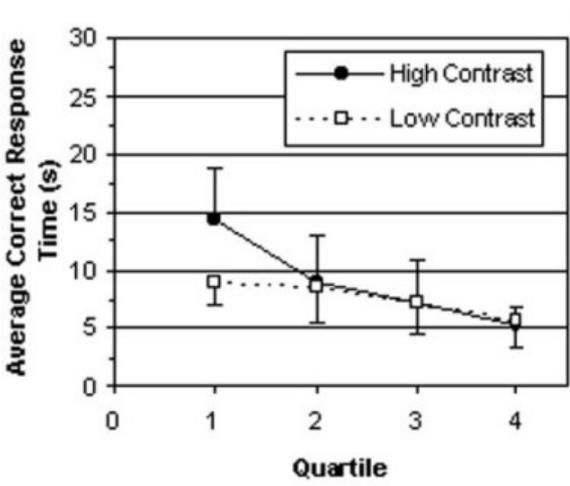
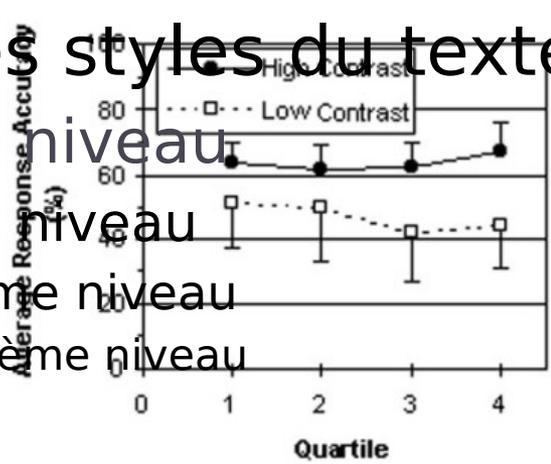


Example of a Snellen chart
Sloan letters for measuring near
vision (40 cm)
acuity in decimal values and in
distance equivalents



Facial Recognition Using Simulated Prosthetic Pixelized Vision

[Thompson et al, IOVS 2003]



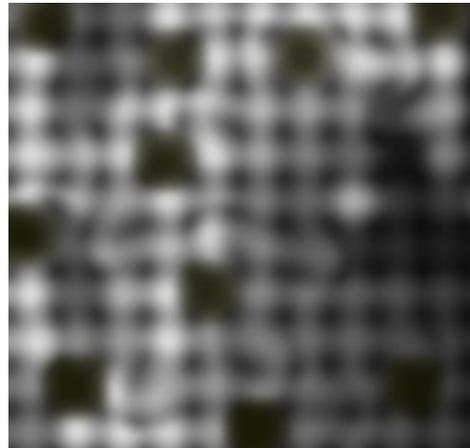
“These findings suggest that reliable face recognition with crude pixelized grids can be learned and may be possible, even with a crude visual prosthesis.”

En suspens

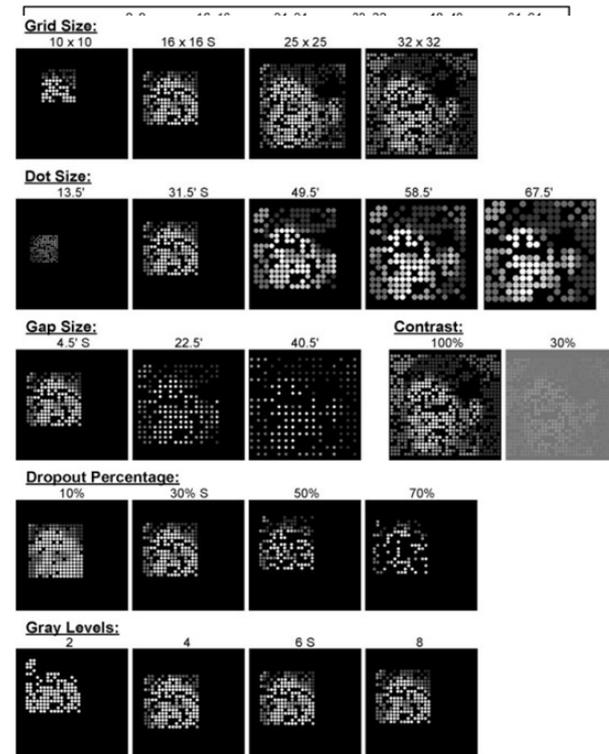
- ▶ Scènes complexes
- ▶ Nouvelles tâches comportementales
- ▶ Mouvement des yeux
- ▶ Phosphènes plus réalistes (forme, taille position, drop-off)
- ▶ Couleur?
- ▶ Algorithmes de segmentation



Rappel



130



Problématiques

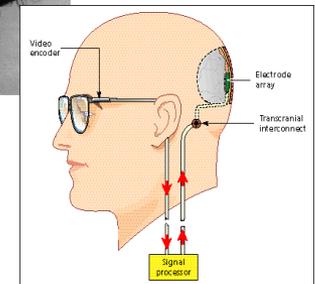
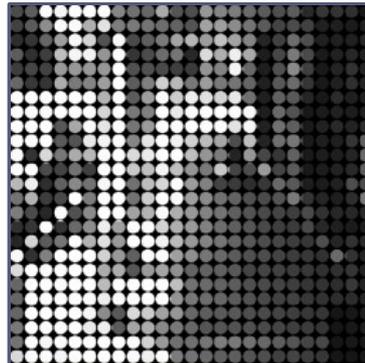
- ▶ Encombrement (taille)
- ▶ Résolution minimale
- ▶ FOV / espacement / configuration
- ▶ Cross-talks
- ▶ Niveaux de gris



Problématique de la vision artificielle



- Score-board
- Interaction non visuelle (substitution sensorielle)
- Interaction neurale



Mobility performance with a pixelized vision system

[Cha et al, Vis Res 1992]

► Modifiez les styles du texte du masque

► Deuxième niveau

► Troisième niveau

► Quatrième niveau

► Cinquième niveau



FIGURE 4. Mobility performance. Walking speed through the maze is plotted as a logarithmic function of number of pixels (100–4096) and field of view (2.0–45.5°). Solid symbols show data from fixed field masks, and open symbols show data from fixed spacing masks. Lines connect points with constant number of pixels or constant field sizes. Each point is the mean from 7 subjects, 5 trials/subject. The plot is shown from two different angles of view to facilitate visualization of the effects of each of the two independent variables.

“The results indicate that a 25x25 (625) array of pixels distributed within the foveal visual area could provide useful visually guided mobility in environments not requiring a high degree of pattern recognition. “

Log(625)=2,8
Log(30)=1,47

Neuroprothèse visuelle

L'oeil et la rétine

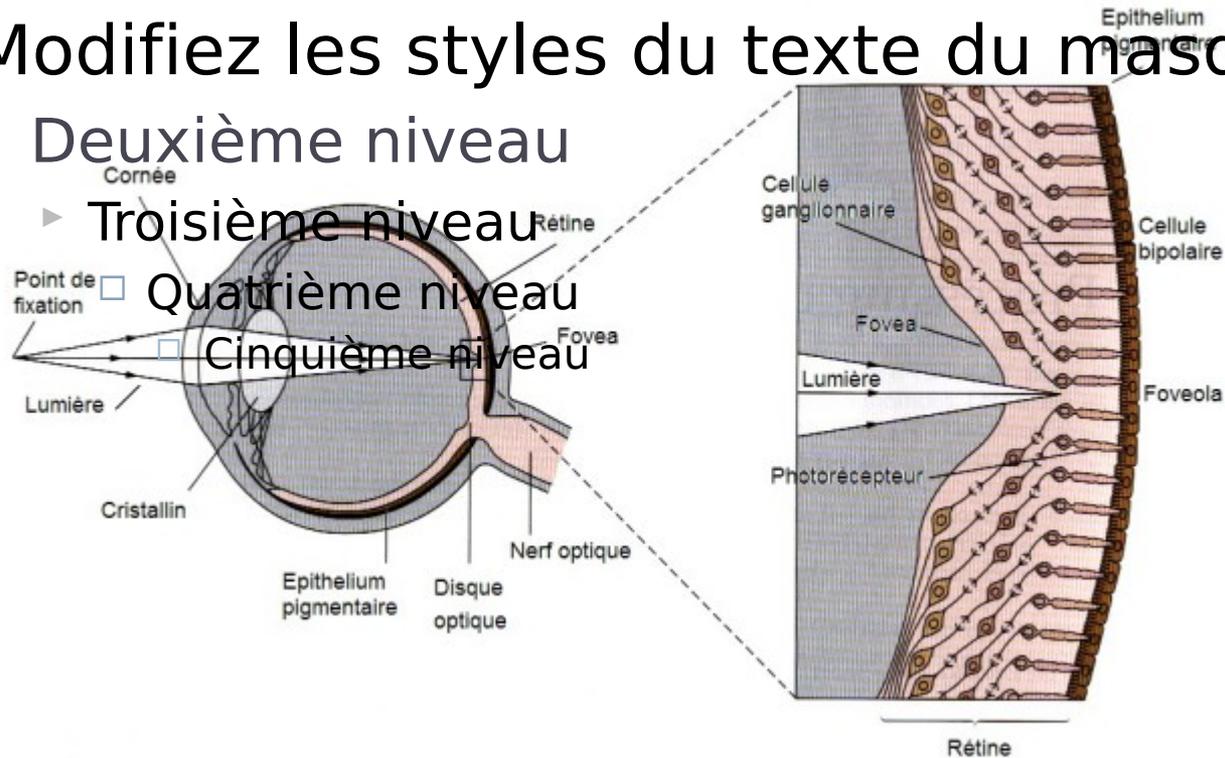
- ▶ Modifiez les styles du texte du masque

- ▶ Deuxième niveau

- ▶ Troisième niveau

- ▶ Quatrième niveau

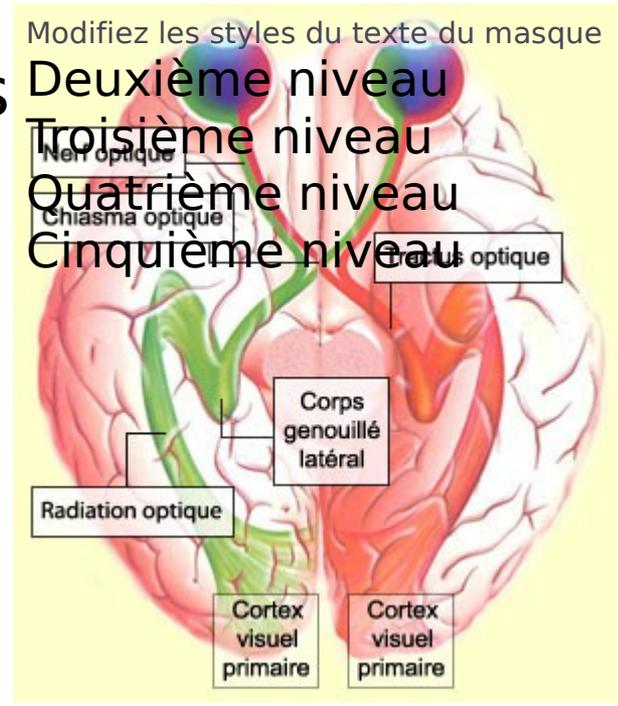
- ▶ Cinquième niveau



Le nerf optique, les relais thalamiques, le cortex



- 3-4 mm de diamètres
- un million de fibres



Stimulations électriques du cortex visuel

- ▶ In 1896, d'Arsonval demonstrated inducing “phosphenes and vertigo” using electrical stimulation.
- ▶ “Foerster (1929) and Krause & Schum (1931) were the first to expose the occipital pole of one cerebral hemisphere and investigate the effect of stimulating it electrically. Foerster found that when a point at the extreme occipital pole was stimulated, his patient saw a small spot of light directly in front and motionless. When a point on the medial surface of the left hemisphere just above the calcarine fissure was stimulated, the patient saw a spot of light that moved a little, but was always in the lower right part of the field. Similar stimulation just below the calcarine fissure gave a similar sensation in the upper right part of the field.”
- ▶ In Brindley & Lewin, J Physiol 1968



Physiologie des aires visuelles

Modifiez les styles du texte du r

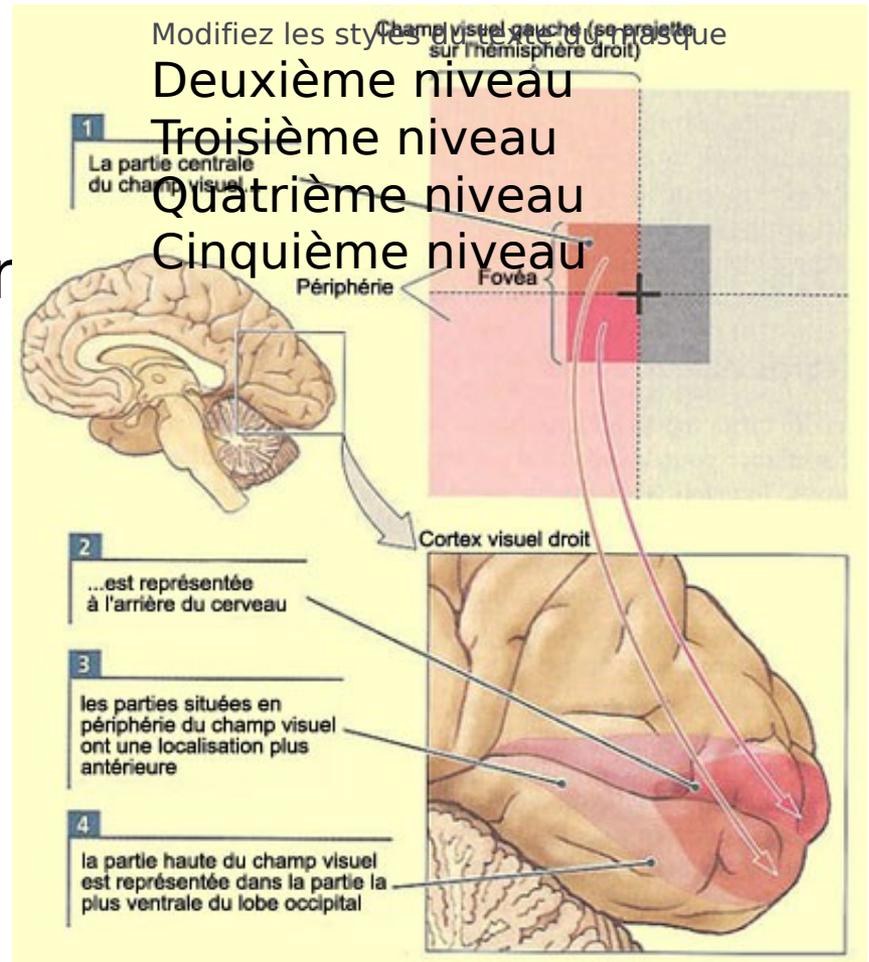
Deuxième niveau

Troisième niveau

Quatrième niveau

Cinquième niveau

Hubel et Wiesel ont reçu le prix Nobel en 1981



Le système visuel

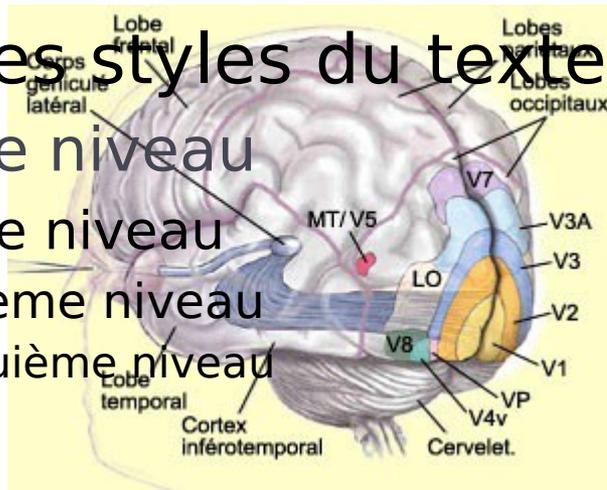
Modifiez les styles du texte du masque

Deuxième niveau

Troisième niveau

Quatrième niveau

Cinquième niveau



Modifiez les styles du texte du masque

Deuxième niveau

Troisième niveau

Quatrième niveau

Cinquième niveau

