Faculdade de Engenharia da Universidade do Porto

# Eye Communication System for Nonspeaking Patients

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VERSÃO PROVISÓRIA

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The present document is based on the work carried out under the direct supervision of the investigator Jean Lorenceau, researcher at Laboratoire des Systèmes Perceptifs de Paris, and the co-supervision of Aurélio Campilho, professor in the department of Electrical and Computer Engineering of Faculdade de Engenharia da Universidade do Porto.

*Jusqu'alors, je n'avais jamais entendu parler du tronc cérébral. Ce jour-là, j'ai découvert de plein fouet cette pièce maîtresse de notre ordinateur de bord, passage obligé entre le cerveau et les terminaisons nerveuses, quand un accident cardiovasculaire a mis ledit tronc hors circuit. Autrefois, on appelait cela « transport au cerveau » et on mourait en toute simplicité. Le progrès des techniques de réanimation a sophistiqué la punition. On en réchappe mais flanqué de ce que la médecine anglo-saxonne a justement baptisé le* locked-in syndrome *: paralysé de la tête aux pieds, le patient est enfermé à l'intérieur de lui-même avec l'esprit intact et les battements de sa paupière gauche pour tout moyen de communication.*

("*Le Scaphandre et le Papillon*", Bauby, 1997)

# Resumo


Após um internamento nas unidades de cuidados intensivos (UCI), os pacientes relatam frequentemente experiências e vivências negativas. A frustração e desconforto sentidos são, em parte, devidos a dificuldades de comunicação causadas pela presença de ventilação artificial e intubação. Uma vez que a capacidade de comunicação por meios convencionais, como a fala e gestos, é limitada, devem ser encontrados métodos alternativos. Até ao momento, não se encontra disponível nenhum método padrão e eficaz para melhorar a comunicação não-verbal nas UCI. O seguimento ocular *(eye tracking)* representa uma solução promissora, uma vez que, mesmo em condições de invalidez severa, o movimento dos olhos é geralmente controlado. Um seguidor ocular *(eye tracker)* é um dispositivo que mede a posição e movimento dos olhos, e pode ser utilizado para interagir ou comunicar com o meio ambiente. Nesta dissertação é apresentada uma revisão da investigação realizada na área de *eye tracking*, desde o momento da sua invenção até aos atuais dispositivos disponíveis comercialmente. Apesar de ter sido reconhecido como um recurso poderoso, há ainda desafios a superar, incluindo o conflito entre a ação de ver e selecionar - *the Midas touch problem* -, calibração, ruído no sinal e limitações ao nível da precisão.

Combinando a informação relativa às necessidades dos pacientes com as vantagens e limitações dos *eye trackers*, pretendeu-se criar um sistema de comunicação com o olhar para pacientes conscientes e intubados ou ventilados. A solução proposta consiste num *eye tracker* e numa interface gráfica apresentando ícones representativos das necessidades básicas e preocupações do paciente. Após uma calibração rápida, o paciente informa a sua intenção/necessidade olhando para o ícone desejado. Este é selecionado após um determinado tempo de observação e um sub-menu é aberto, a fim de especificar a opção anterior. Testes de usabilidade foram efetuados em pessoas saudáveis, de forma a validar a funcionalidade do sistema de comunicação. Os movimentos oculares foram registados durante a visualização da interface gráfica, e foi realizado um inquérito de forma a avaliar a experiência dos utilizadores. Relativamente aos desafios inerentes à utilização do *eye tracker* como periférico de entrada, foram propostas e testadas diversas soluções que se revelaram adequadas e funcionais.

Os resultados obtidos através dos testes de usabilidade confirmam a funcionalidade do dispositivo médico e viabilizam a passagem para a fase de teste em pacientes. Assim, após um processo de regularização a nível de segurança e saúde, uma equipa de especialistas de pneumologia do Hospital de Pitié-Salpêtrière em Paris, irá avaliar o contributo do dispositivo médico na comunicação não-verbal e na redução das fontes de desconforto do paciente.

# Abstract

A stay in an intensive care unit (ICU), although potentially life-saving, may be a traumatic experience to patients. The frustration reported is partly due to communication difficulties caused by the presence of artificial ventilation and intubation. Once the ability to communicate by conventional ways, as speech and gesture, may be limited, alternative methods must be found. So far, there is no standard, reliable and effective tool to improve non-verbal communication in the ICU. Eye trackers represent a promising solution, since even in high disability conditions, eye movement is usually controlled. An eye tracker is a device for measuring eye's positions and movement and can be used to translate the intention of the person into functional interactions or as a communication way with the surrounding environment. This work, presents a review of the research carried out in the eye tracking field, since the moment of its invention to the current and commercially available devices. Although it has been proved to be a powerful solution, there are still challenges to overcome, including the conflict to distinguish casual viewing from the desire to produce intentional commands - "the Midas Touch" problem -, calibration, noise and accuracy issues.

Combining the information concerning the patient's needs with the advantages and limitations of eye trackers, we intended to create a system to communicate with the eyes addressed to conscious and intubated or ventilated patients. The proposed solution consists on an eye tracker and a graphical user interface displaying representative icons of the basic needs and concerns of the patient. After a quick calibration, the person just needs to look at the desired icon on the screen to select it and subsequently open a sub-menu in order to specify the previous choice. Usability tests were performed to access the functionality of the communication system. Eye position was recorded during observation of the graphical user interface and a survey was conducted to evaluate user's experience. Solutions were proposed and tested addressing the challenges inherent the use of eye tracking as an input device and the outcomes confirm its validity and effectiveness.

The results obtained from the usability tests confirm the functionality of the medical device and enable the transition for the testing phase in patients. After safety and health regularization, a team of pulmonology specialists from the Pitié-Salpêtrière hospital in Paris will access the contribution of the medical device to facilitate non-verbal communication of the patient, assessing patient´s discomfort and the efficiency of the device on reducing its sources.

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# List of Abbreviations

| | |
|---|---|
| AAC | Assistive and Alternative Communication |
| ADOREPS | Organisation de la Recherche en Pneumologie et sur le Sommeil |
| ALS | Amyotrophic Lateral Sclerosis |
| APHP | Assistance Publique Hôpitaux de Paris |
| API | Application Programming Interface |
| ATICE | Adaptation To Intensive Care Environment |
| CAM-ICU | Confusion Assessment Method for the Intensive Care Unit |
| COGAIN | Communication by Gaze Interaction |
| CPP | Commité de Protection des Personnes |
| EOG | Electro-Oculography |
| EOL | EyeOnLine |
| GUI | Graphical User Interface |
| HCI | Human-Computer Interaction |
| ICU | Intensive Care Unit |
| IP | Internet Protocol |
| IR | Infra-Red |
| JSON | JavaScript Object Notation |
| SGD | Speech-Generating Device |
| SLP | Speech Language Pathologists |
| TCP | Transmission Control Protocol |
| VOG | Video-Oculography |
| WPS | Words Per Second |

# Chapter 1

# Introduction

"Communication is recognized as an essential human need and, therefore, as a basic human right. Without it, no individual or community can exist, or prosper." (Centre for Communication Rights – CCR, 2011). Communication is the meaningful exchange of information between two or more living creatures through expression forms that include speech, signals, writing, or behaviour. Part of the civil and scientific responsibility is to provide communication access to all individuals, even if they are unable to achieve it on their own.

## 1.1 Motivation

Each year, seven million people in the European Union are admitted to medical and surgical Intensive Care Unit (ICU) (European Parliament Statistics, 2014). More than one-third of those patients experience inability to speak because of intubation or mechanical ventilation (Fowler, 1997). This condition may cause feelings of panic and insecurity, sleep disturbances and stress levels (Bergbom-Engberg & Haljamae, 1989). Nurses also report impotence when patients are unable to express their symptoms, pain levels and needs (Alasad & Ahmad 2005). Occasionally, hospitalizations with expected duration of 2-3 days are extended, increasing the patient's stress. Better understanding and interpretation of intentional messages of patients may improve assessment of symptoms, selection of treatments and even facilitate the expression of important thoughts and sentiments at the end of life. Besides, it is widely accepted that psychosocial factors are related to illness behaviour, and there is some evidence that they may influence the rate of recovery from post-traumatic disorders (Radanov *et al.*, 1991). Therefore, it is of general interest to avoid acute stressful states, as it will improve patients' health conditions and the overall logistics of the hospital system.

Literature demonstrates that providing assistive and alternative communication (AAC) strategies might enhance patients' daily interaction and by extension, clinical outcomes (Patak *et al.*, 2006). Although the problems associated with the inability to speak during critical illness have been clearly established, few solutions have been offered or systematically tested with ICU patients (Happ, 2001). The movement of the eyes can be used as an alternative communicating method for patients in the ICU who are unable to speak.

The eyes are one of the most expressive features of the human body for non-verbal implicit communication. The human gaze is postulated to be the best indicator for attention or intention (Dalton & Ellis, 2003). Besides being a source of information, the eyes have very fast and thorough movements (Krauzlis, 2005).

In the last century, eye tracking systems have had a significant evolution and offer, nowadays, a wide range of possibilities and different technical features, operating modes and application fields (Dongheng Li, 2006). Eye trackers have been employed in several areas, ranging from the fundamental scientific research to practical applications for Human-Computer Interaction (HCI). Therefore, an eye tracking system can be a powerful solution to solve the aforementioned communication problems of patients at ICU.

The present work was conducted within the Laboratoire des Systèmes Perceptifs, at École Normale Supérieure in Paris, integrated in the EyeOnLine (EOL) project and based on the past experience of the team of Jean Lorenceau in eye tracking systems. The research was developed in collaboration with a medical team from the Pulmonary Service of the Pitié-Salpêtrière Hospital. The evaluation of the medical device will be conducted by Doctor Camille Rolland-Debord in collaboration with Professor Alexandre Demoule.

## 1.2 Objective

At the moment, there is no standard, reliable and effective tool to facilitate the non-verbal communication between patients and the medical personnel in the ICU. The main objective of this study is to develop a medical device to improve the communication ability of patients who are intubated or receiving mechanical ventilation. It will be applied an eye tracking system to control a graphical user interface (GUI) for communication with the eyes. The main concern is to inform patients' symptoms, pain levels and needs in order to access their health condition and improve their day life at the hospital.

An overhaul of the current assistive technologies, in particular eye trackers, as well as a general knowledge of the anatomy and physiology of the eye, is needed to better understand the functioning of these systems.

Since this technology is directed to people at debility states, reliability, robustness, safety, and mounting issues must be carefully taken into account. Its interface must be intuitive, once the direct users will be patients of different ages and education levels. It is also desired an attractive and playful design in order to encourage its usage.

The device will be handled primarily by paramedics, so it is intended to be practical and easy to implement, in order to not be an extra charge on paramedics' working routines.

Preliminary tests conducted in healthy subjects will confirm the functionality and usability of the system. Finally, to evaluate the contribution of the medical device in facilitating non-verbal communication with the patient, a team of pulmonology specialists will assess patient discomfort, evaluate the intensity of the target discomfort and analyse the effectiveness of the medical device on reducing discomfort sources.

## 1.3 Contributions

A medical device for communication via eye movements targeting nonspeaking patients at ICU was created.

It was developed an application to integrate an eye tracker on the current system and extract the user eye's position.

A graphical user interface was designed to easily express patient's symptoms, feelings and needs through the navigation on menus.

An experimental protocol was elaborated to test healthy subjects while using the graphical interface developed in this work. A survey was conducted afterwards to evaluate the user's experience. The data collected during these different tests was analysed and discussed.

A user's manual of the respective medical device was elaborated to be included into the health and safety regulation document.

## 1.4 Dissertation Overview

This dissertation is divided in six chapters including: Introduction, Augmentative and Alternative Communication in the ICU, Eye Tracking, The Eye Communication System, Results and Discussion, Conclusions and Future Work.

The Introduction describes the motivation, the main objectives, my contribution to this work, and finally, the present overview of the dissertation organization.

Chapter 2 describes the problem which was the motivating engine of this research. It provides an overview of the actual discomforts and communication problems felt by patients at ICU, to better describe the underneath concern. The major topic is related to augmentative and alternative communication techniques directed to patients at intensive care units. It also gives a picture of the context to where it was created for - the Pitié-Salpêtrière hospital - in order to better characterize the target population.

Chapter 3 starts with a short description of the eye anatomy and physiology and it provides a definition of eye tracking followed by its history. After, it describes the existing systems and technologies for eye tracking, focusing in the most common video-based eye trackers. Furthermore, it addresses the application of eye trackers as a scientific tool and for Human-Computer Interaction, discussing the current input eye tracking challenges and giving some examples of eye writing systems. In this chapter is also introduced the eye tracker used in this project, The Eye Tribe™.

Chapter 4 describes the medical device created to accomplish the defined objectives. In short, it provides the methodology used in the development of the system and its general operating mode. Herein are also described the usability tests performed in order to evaluate the functionality of the device. It also delineates the regulatory issues to implement the medical device in the hospital.

Chapter 5 reports the results and discussion of the usability tests carried out in healthy subjects. It analyses the user's eye position recordings during the graphical user interface observation and the survey conducted after system usage.

Chapter 6 discusses the potential features to be improved and outlines directions for future research.

# Chapter 2

# Augmentative and Alternative Communication in the ICU

Augmentative and Alternative Communication (AAC) encompasses the methods used to supplement or replace the production and/or comprehension of spoken or written language. It is addressed to individuals with temporary or permanent impairments, activity limitations, and participation restrictions that constrain the normal speech-language (American Speech-Language-Hearing Association, 2005).

After staying in the Intensive Care Unit, the survived patients have often painful memories of this experience. Such is caused naturally by the pain and discomfort arising from their health condition, but also due to a communication failure between the patient and the health personnel. In this chapter the main causes of patient's discomfort in the ICU will be set out to characterize the problem and ascertain the major concerns of this study. The existence of a communication failure between patients and medical personnel creates a need for communication resources.

This chapter addresses AAC technologies targeting patients in the ICU, reviewing the current methods and analyzing viable solutions.

In order to be aware of the problem's scale, it is necessary to locate it in the physical context of study. In this case, the medical device will be applied in the pulmonology service of the Pitié-Salpêtrière hospital, hence an overview of the key numbers of this service is necessary to understand the complete picture of the clinical need.

## 2.1 The Need for AAC

In the past century, the need for assistive technologies including AAC has increased. Improved care of low-birth-weight infants has augmented the number of survivors with severe impairments, many of whom eventually require assistive technologies for communication, mobility and education (Tudehope *et al.*, 1995; Watts & Saigal, 2006). The expanding population of older adults is accompanied by a growing burden of disability and increased demand for alternative access strategies (Guralnik, Fried & Salive, 1996). In addition, it is established that individuals with severe impairments can survive for many decades, requiring assistive technologies for longer periods and for more delicate health conditions (Doble, Haig, Anderson & Katz, 2003).

Some individuals can be physically limited and medically fragile for a short-period while others live out their lives in assisted living or skilled nursing facilities. In both cases, AAC technologies play a key role in the individual's short- and long-term quality of life.

Among the various origins of severe motor impairment, the assistive technologies aim for people suffering from locked-in syndrome, amyotrophic lateral sclerosis (ALS), quadriplegia, muscular dystrophy, cerebral palsy and many others. The limited independence of individuals with severe and multiple physical disabilities, whether congenital, traumatic or disease-induced, can be mitigated with alternative means of interaction with the surrounding world.

Depending on the type and the progress level of disability, different strategies may be adapted to each patient. For non-verbal individuals limited to fine motor control above the neck, eye trackers or computer vision-based face tracking systems may facilitate communication and environmental control. For people with severe motor disabilities, eye gaze may be the only option available for communication. In the late stages of some neurodegenerative diseases, control over all other body movements may be lost, but the person can still move the eyes. For example, people with ALS have normally good visual, cognitive and literacy skills and also do not have involuntary movements, making the eye tracking suitable. For people with involuntary movement as a result of cerebral palsy or other disabilities, eye movements can seem difficult to track. However, some studies reveal that even for these people, and for those who have visual or learning difficulties or other physical interference which would limit the effectiveness of older eye control systems, eye tracking is a viable solution (Cometa *et al.*, 2011).

## 2.2 The Discomfort in the ICU

The discomfort felt by patients at ICU can cause anxiety both during and after the permanence at the hospital. The syndrome of post-traumatic stress disorder is a well-established sequelae after hospitalization and its mitigation is crucial (Cuthbertson *et al.*, 2004).

The presence of amnesia in some cases can complicate the collection of a posteriori experience of intensive care stay (Van de Leur *et al.*, 2004). However, several studies concluded that the main factors responsible for discomfort are pain, disorientation, breathing difficulty, incapacity to move, painful medical procedures and the presence of an endotracheal tube. Between the environmental sources of discomfort, patients refer frequently noise, luminance, lack of sleep, thirst, hunger, cold, among others.

Pain is a major source of stress as it causes sleep problems, restlessness and the onset of *delirium*. It represents the most common source of negative memories from the ICU experience once its detection may not be immediate. Nevertheless, the main causes are normally drains, probes, endotracheal aspirations, arterial and venous punctures, mobilization and postoperative pain (Pandharipande *et al.*, 2014; Chanques *et al.*, 2006).

Dyspnea is another factor that is reported in about half of the patients at ICU (Schmidt *et al.*, 2014). There are several sensations of dyspnea described currently as the feeling of shortness of breath. Studies demonstrate that symptoms indicative of post-traumatic stress disorder are correlated with memories of respiratory distress and mechanical ventilation for long periods (Cuthbertson *et al.*, 2004). Therefore, dyspnea may be one of the traumatic events involved in the genesis of a state of post-traumatic stress.

Inability to communicate, dependency and vulnerability are also described as stressful and isolating, making the identification of discomfort sources even more difficult (Nelson *et al.*, 2001; Rotondi *et al.*, 2002). In the particular case of patients who have undergone medical interventions of the respiratory tract, there are many obstacles to their verbal communication, namely the pathology itself, the endotracheal tube and the surrounding agitation.

The verbalization difficulty also depends on the severity of the condition and the state of consciousness of the patient. Discomfort and isolation feeling is increased by the lack of explanations given to the patient about their health state (Novaes *et al.*, 1999). Due to intubated patients' inability to communicate, it is easy to misunderstand their desires, and thus do not meet their expectations (Radtke *et al.*, 2011).

In intubated and ventilated patients at end of life, the content of communication relates mainly to pain, emotions (stress, anxiety, loneliness, frustration), the existence of physical symptoms (dyspnea, nausea / vomiting, asthenia, sleep) and physical needs (hunger, thirst, position in bed). In these patients, communication difficulty is worsened due to the workload of the caregivers, to the patient's inability to write, difficulty in reading patient's lips and the lack of training of the healthcare team (Happ, Tuite, Dobbin *et al.*, 2004).

## 2.3 Current AAC Technologies

People that are at ICU may lose temporarily the ability to speak and short-term solutions may be applied. In certain cases, patients are unable to communicate due to oral or tracheal intubation, but once the tubes are removed they are able to vocalize again. For that reason, permanent or difficult and time-consuming methods are not suitable at ICU.

Descriptive studies have demonstrated the benefits of using AAC intervention approaches at ICU, such as gestures, writing, partner-assisted scanning, communication boards, digitized and synthetized speech generating devices, Yes-No and other signals (Fried-Oken, Howard & Steward, 1991; Radtke *et al.*, 2011; Costello, 2000; Menzel, 1998; Blackstone, 2007).

In one study of Radtke *et al.* speech language pathologists (SLP) were responsible for providing AAC assistance to nonspeaking patients at ICU (Radtke *et al.*, 2011). Three clinical cases illustrated the application of different AAC strategies according to the levels of illness severity and communication impairment. Low-tech AAC strategies, such as supplemented speech, written choice communication, and picture communication boards controlled by pointing, mouthing and Yes-No head nobs, proved to be highly effective, easily implemented and low-cost. Electronic speech-generating devices like DynaMyte™ (DynaVox Technologies Inc., Pittsburgh, Pa) and Lightwriter™ (Toby Churchill Ltd.) were also successful, allowing a fast communication and a large availability of topic messages. DynaMyte provides a touch-screen with active message "buttons" that are represented by pictures and words, organized by common topics (eg. "feelings", "help", "people") (Figure 2.1 on the left). Once selected, the message is spelled out via synthetized speech. Novel messages can also be generated via a touch-screen keyboard and reproduced loudly (Figure 2.1 on the right).

**Figure 2.1** - The DynaVox device. On the left, the predefined "buttons" mode and on the right the free message composer through touch-screen keyboard. The final messages are reproduced loudly via digitized speech by the speaker visible on the right image (DynaVox, 2014).

The Lightwriter provides an alphabet and numeric physical keypad to produce messages beyond the common available topics (Costello, 2000). This device also reproduces the desired message by synthetized speech and provides a two-sided LCD that displays the message to both writer and receiver (Figure 2.2).


**Figure 2.2** - The Lightwriter SL40 model. The device has two-sided LCD screen that displays the message to both writer and receiver and a speaker to reproduce the message loud via digitized speech (Toby Churchill, 2014).

These devices require fine motor control and concentration which might be not suitable in all cases. Finally, in all patients, the SLP attempted trials with a tracheostomy speaking valve. The rationale for a one-way speaking valve is that air must pass over the vocal cords to regain speech. Only two patients produced intelligible words using the speaking valve, although long phrases were mostly unintelligible due to severe illness. These cases illustrated that providing communication devices and SLP consultation may offer additional communication support, enhance communication outcomes, and add value to the intensive care services.

Fried-Oken *et al.* showed that alphabet and picture boards were preferred over electronic devices by 4 of the 5 ICU survivors interviewed about their experiences with AAC in ICU (Fried-Oken, Howard & Steward, 1991). Approaches that required significant learning effort by the user and listener were not recommended. In this study, electronic devices appeared to be the last option for most patients. In the same lines, Dowden *et al.* showed that natural approaches (gesture, writing and mouthing words) were more frequently used than any other type of medical device to improve communication (Dowden & Marriner, 1995).

In fact, most nonspeaking ICU patients may use more than one technique or strategy during their ICU stay. Multimodal or combined solutions and customized AAC techniques have become the standard of care in AAC practice (Reilly & O'Malley, 1999). Garrett *et al.* suggested developing "AAC kits" for ICUs to provide personalized speech and language services for each patient. See table 1 for a partial list (Garrett *et al.*, 2007).

**Table 2.1** — Suggested AAC equipment and supplies to be used at ICU (Garrett *et al.*, 2007).

| | |
|---|---|
| **Writing materials** | Spiral bound notebooks OR brightly coloured clipboards and tablets. Clipboards that hook over the bedrails. Felt-tip pens. Long strips of Velcro to attach pens (affix one end to clip, attach other to pen cap). Flexible pencil grips or orthotic writing aids. Universal elastic cuff. |
| **Written choice communication notebooks** | Include a cover card. Outline of country map. Preprinted opinion scales. |
| **Communication boards** | Yes/No boards. Needs/emotions boards. Alphabet boards (in various sizes). Symbol set(s) and posterboard for family-made communication boards. |
| **Partner dependent scanning notebooks** | Include a cover sheet with instructions. Topic lists. Message pages. Alphabet page. |
| **Eye gaze communication board set** | Blank overlays. Alphanumeric overlays. Choice boards. Yes/No overlay. Clear plexiglas display board (optional). Erasable markers. Adhesive notes for novel choices. Metal rings to hold or store overlays. Poster board for encoded message chart. |
| **Electrolarynx with oral adapter** | With audible quality and volume control. Relatively moisture-proof housing. Disposable oral tubes. |
| **Simple SGDs with digitized voice output** | Preferred features are computer screens (rather than paper displays), bright screens, sealed housing. Purchase waterproof "skin" for device. |
| **Complex, multi-level SGDs with visual and auditory scanning capability** | Preferred features are bright screen display, light weight, durable, moisture-proof screen, easy to program. |
| **Hand-held electronic spelling device or spelling-based AAC device** | |
| **Switches** | Large, medium and small touch plate. Lever. Piezoelectric and/or infrared. Pillow. Squeeze. Sip-and-puff. |
| **Switch and device mounting equipment** | Weighted poles for hanging low-tech and lightweight high-tech devices, communication information posters, patient's signal chart and gesture dictionaries. |
| **Miscellaneous supplies** | Velcro. Metal recloseable rings in various sizes. Plastic page sleeves for communication boards and overlays. Poster board and markers. Clear plastic mailing tape for affixing labels. Ties for attaching items to IV poles, triangle pulls or bedrails. |

As shown in table 2.1, there are several approaches that can be applied in the ICU. The hospitals cannot provide the entire range of methods and normally the medical unit cares have available only one or two options that might not be suitable in all the cases and for all the patients.

## 2.4 Communication Tools

Communication tools have been developed to help people to interact with the surrounding environment. Communication aids include communication boards, voice output communication aids, adapted computers and devices that facilitate access to computers such as alternative keyboards, switches and software. Both for low technology approaches, such as the communication boards, or for more complex devices, there must be an universal and not ambiguous language, so that patients can communicate their wishes and needs without misunderstandings.

If the individual is able to spell and write, he can use keyboards with letters and digits to express an idea or a desire. Whether is not suitable, or in case of wanting a faster and more objective communication, the alphabet can be replaced by pictures, words or a combination of both. Typically, these techniques are developed to address both specific and generic vocabulary needs in a variety of contexts. However, sometimes, the communication boards have infant-like pictures that do not please adult patients and may discourage their use.

Depending on the level of cognitive and physical ability of the patient, the communication templates can be more or less complex and comprehensive. Some approaches can allow the individual to organize the objects/actions, to store the most used ones, or even to create hierarchies to faster achieve each item. For experts, the communication board can be more complete so that the user can express almost everything in an efficient and rapid way. This approach can support a full range of input methods, from keyboard and mouse input, to scan, switch, head mouse and eye control. Currently, there are available several communication boards either in a physical support or as software to incorporate in specific devices or even common computers/tablets. Tobii Communicator™ is an example of software created for day life communication, featuring symbols and pictures for users who cannot write (Tobii Comunicator™, 2014). Figure 2.3 shows an example of template that can be personalized for multiple user profiles.


**Figure 2.3** - Communication board displaying symbols and words representing objects and/or actions (Tobii Comunicator™, 2014).

## 2.5 The Context of the Pitié-Salpêtrière Hospital

The development of the present project aims the intensive care unit of the Pitié-Salpêtrière Hospital. The APHP (Assistance Publique Hôpitaux de Paris), including 44 hospitals, is considered to be the largest hospital complex in Europe, and occupies the eighth position worldwide. The Pitié-Salpêtrière, with more than 400 years of existence, is the largest hospital of APHP.

Some key numbers about this hospital and its patients in 2012 are listed below (APHP, 2014):

- 2 132 beds
- 11 poles of distributed activities
- 87 713 number of short period stays (<24h)
- 64 693 number of long period stays (>24h)
- Average duration of hospital stays: 5 days.
- 53% of the patients are intubated and ventilated via a breathing tube.
- 32% of the patients are under non-invasive ventilation via a breathing mask.

Hence, it can be concluded that, for about 85% of the patients, it is impossible to communicate by verbal language due to the physics constraints (intubation, artificial ventilation, mask...).

The pulmonology service of this hospital is included in the pole “PRAGUES” shared with Anesthesia, Geriatrics, Emergencies and Explorations of the Pulmonary function. Within this pole some of the key numbers are listed below:

- 152 beds
- 2 591 number of short period stays (<24h)
- 13 505 number of long period stays (>24h)

Considering that this system will be applied, in a first instance, to patients at pulmonology department with long period stays at ICU, we can compute that this will be available for about 10 000 patients per year, just in this hospital. Once approved by the national health system, this communication method can be applied in other hospitals in France or even in the world. Thus, the developed device shows enormous potential in improving the quality of life of millions of patients around the world.

## 2.6 Concluding Remarks

According to the previously published literature, pain, anxiety and dyspnea are the most referred discomfort sources during a patient's stay in the ICU.

The problem was studied with the medical team of the Pitié-Salpêtrière Hospital, which selected nine needs considered to be priority at ICU:

- Pain
- Anxiety
- Lack of air
- Excessive respiratory effort
- Need to be aspired
- Desire to be informed about their health state
- Bad installation
- Thirst

Numerous studies demonstrated that the use of AAC techniques in the ICU increases patient's sense of control and emotional health and may have a positive impact on healthcare outcomes.

A literature canvas proved that, to date, the current techniques to improve communication in the ICU do not meet the needs of patients and caregivers. Several reasons can explain this:

- the lack of a consensus validated technique on a sample of patients,
- for some of them, the need for learning is in practice not feasible at ICU because it would require hospitalization programming,
- difficulties related to the presence of contention or myopathy can limit gesture,
- additional workload for medical and paramedical personnel,
- significant expenditures in high technologies,
- infant-like communication language.

Concluding, for critically ill patients that are either intubated or mechanical ventilated, there is, so far, no standardized reference system neither an effective available tool to improve non-verbal communication in the ICU.

In this sense, this work aims to develop a new tool which overcomes the constraints of the ICU stay, based on the detection of eye movements.

The aforementioned needs will be included in medical device setting and ultimately, they will be the object of assessment when testing the device at the hospital. Besides those, other items will be included namely hunger, anxiety and TV control as suggested by medical professionals.

The analysis of the current number of patients at Pitié-Salpêtrière hospital, has shown that there is a large population of people who can potentially benefit from this system.

# Chapter 3

# Eye Tracking

After discriminating the problem and the need, it is time to propose a viable solution. This chapter will demonstrate how eye tracking can be an answer to the previously described problem, providing a review of the current methods and analysing the advantages and disadvantages of this technique.

Eye tracking is a technique whereby the individual's eye movement is measured, so it is possible to know both where a person is looking at any given time and the motion of an eye relative to the head. An eye tracker is a device for measuring eye's positions and movement, as well as eye features such as pupil diameter and blink rate (Poole and Ball, 2005).

Video-oculography (VOG) and electro-oculography (EOG) are the main technologies incorporated into commercially available eye trackers. The eye trackers market is dominated by video-based trackers due to their non-invasiveness and high accuracy (Bates, 2006).

Eye movement information can be applied into two strands. Firstly, it can provide an objective source of how individuals observe the scenery and what kind of eye movements are performed in specific contexts. Eye trackers are powerful tools in scientific research of the visual system, psychology, cognition, medical diagnosis and rehabilitation. Additionally, they can be used in market research and advertise testing, providing user evaluation data and clues as to design more attractive brand images (Dongheng Li, 2006).

Secondly, eye movement information can be applied in Human-Computer Interaction (HCI) research, either in usability-evaluation studies to enhance the user-friendliness of interfaces, or for capturing people's eye movements as an input mechanism to control system functions. This represents a major advantage for certain populations of users who are temporarily unable to communicate verbally or even permanently unable to move their limbs (Pinheiro, 2011).

## 3.1 Anatomy and Physiology of the Ocular Motor System

To study eye tracking systems, it is necessary to comprehend both sides of the interaction – the eye tracker and the human eye. Before describing in detail the first one, this section will present general knowledge about the eye anatomy and physiology, in order to understand the basic principles that will be developed in the next chapters.

The eye is the organ responsible for the vision, by detecting light and converting it into electrochemical impulses in neurons.

### 3.1.1 Eye Anatomy

The eye is not shaped like a perfect sphere, being rather a fused two-piece unit (Horn & Leigh, 2011). An image of eye anatomy is shown in figure 3.1, depicting a right-eye from the front and inside point of view.

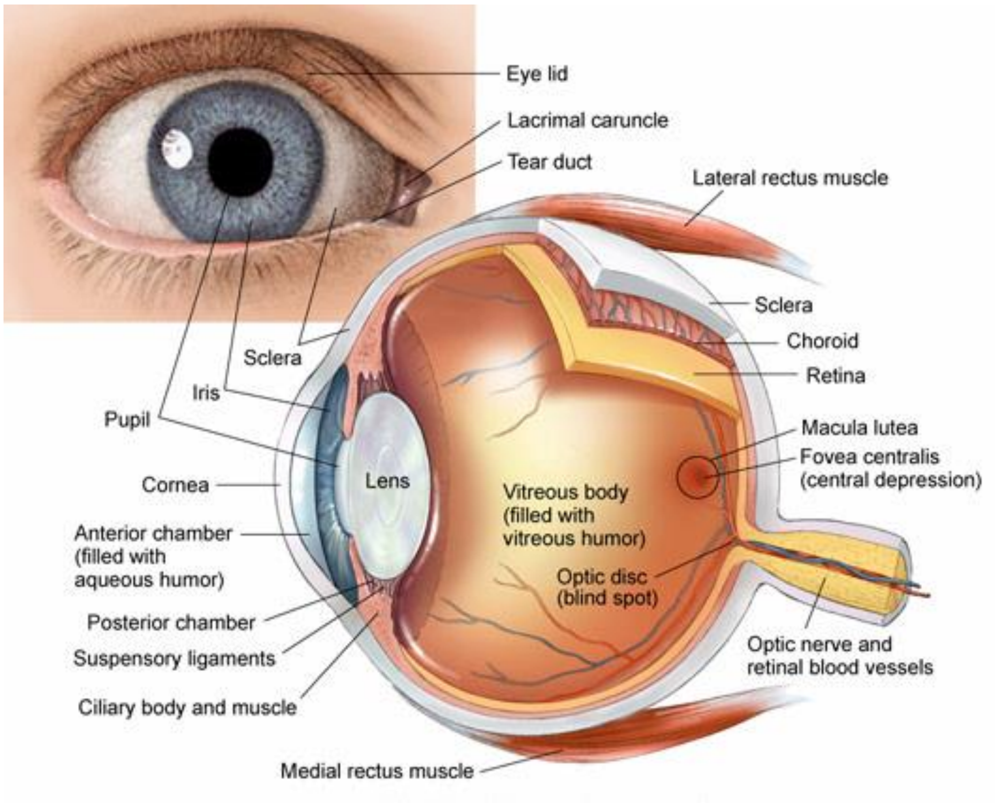


**Figure 3.1** – Right eye viewed from the front and cross section of the eyeball viewed from above (Custers, 2014).

The smaller frontal unit, more curved, is called the cornea and is linked to the larger unit called the sclera. The cornea is a transparent coat that covers both the pupil and the iris. This is the first and most powerful lens of the optical system and allows, together with the crystalline lens, the production of a sharp image at the retinal photoreceptor level. The sclera forms part of the supporting wall of the eyeball and appears white in the eye image.

The cornea and sclera are connected by a ring called the limbus that surrounds the iris (Judd & Wyszecki, 1975). The iris, the coloured part of the eye, is a circular muscle that controls the size of the pupil so that more or less light, depending on the environmental conditions, is allowed to enter the organ. This aperture appears dark because of the absorbing pigments in the retina.

The sensory part of the eye, the retina, has two different types of light sensors: rods and cones. While rods have a high sensitivity to brightness and enable night vision, the cones are less sensitive and detect chromatic light. Most parts of the retina have a very low density of light receptors, and only a small circular area with a diameter of 1º to 2º, called fovea, has a high density of cones. Everything inside this region is seen in detail, while everything outside this narrow field is seen indistinctly. Thus, people see only a small portion of any full scene accurately in time. This narrow vision generates the need to move the eyes rapidly around to form a full view of the world.

### 3.1.2 Eye Movements

Each eyeball is rotated by six extraocular muscles that are organized as antagonistic pairs and give three degrees of freedom. One pair is responsible for horizontal movement, another pair controls the vertical movement, and the third pair allows rotational movement around the direction of view. Figure 3.2 depicts the three types of eye's muscles responsible for the different movements.

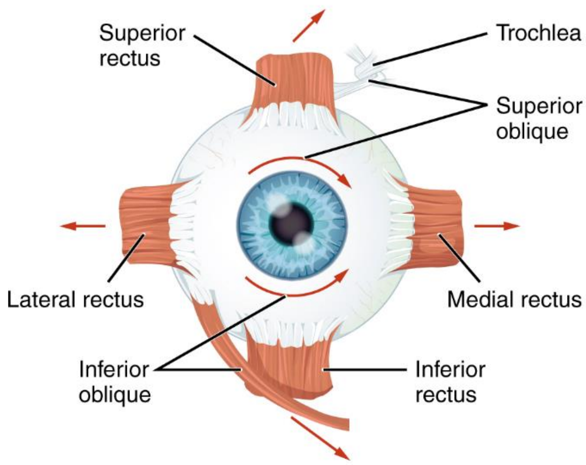


**Figure 3.2** – Anterior view of the right eye showing the three types of muscles that provide the different movements (OpenStax CNX, 2014).

Eye movements are divided into six different types, each of which performs a specific, quantifiable function. The six types are: fixations, saccades, smooth pursuit, vergence, vestibular and optokinetic (Sharpe & Wong, 1986).

Fixations are the moments when the eyes are relatively immobile, holding the image of a stationary target on the fovea to encode the displayed information (McConkie *et al*. 1988).

Saccades are discrete ballistic movements occurring between fixations. The purpose of most saccades is to move the eyes to the next viewing position. Visual processing is automatically suppressed during saccades, to avoid blurring of the visual image.

Figure 3.3 presents a famous picture of the pioneering study made by Yarbus showing how eyes scan a human face through fixations and saccades (Yarbus, 1967).

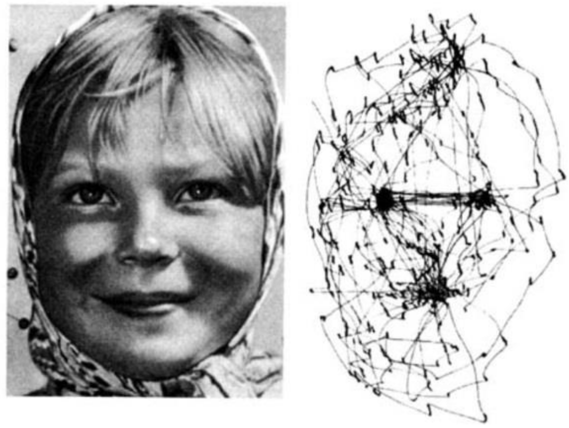

**Figure 3.3** – Eye movements while watching a girl's face (Yarbus, 1967).

Smooth pursuit is performed while eyes are tracking an object's movement, so that its moving image can be retained on the fovea. It compensates the motion of the visual target and, thus, minimizes the drift of the target's image across the retina that could otherwise blur the image and compromise visual acuity.

Optokinetic helps to stabilize the eyes during head and body movements by minimizing the motion of the entire visual surrounding field.

Vestibular movements stabilize the image on the retina during brief head movements, helping to maintain the vision clear.

Vergence occurs when eyes move in opposite directions so that images of a single close target are placed simultaneously on both foveae.

Considering eye movements in smaller time and length scales, drift, tremor and microsaccades can be also mentioned. These small movements occur even during fixations to keep the nerve cells in the retina active and to correct slight drifting in focus (Engbert & Mergenthaler, 2006). Several measures can be extracted from these basic movements, such as the gaze, which corresponds to the sum of all fixation durations within a prescribed area. The main measurements used in eye-tracking research are fixations, saccades and smooth pursuit movements. Gaze, pupil size and blink rate are also studied (Poole *et al.*, 2005).

The typical duration of each movement is naturally different. While fixations last for 218 milliseconds on average, with a range of 66 to 416 milliseconds, saccades typically last for 20 to 35 milliseconds (Poole *et al.*, 2005).

Some studies have demonstrated that the eye's dynamics may be influenced by the kind of activity performed by the person, namely by the regular practice oh high level sports (Williams, 2002). More recently, investigations have shown that the control of some kind of eye movements may even be learnt specifically the smooth pursuit eye movement as it will be demonstrated hereafter (Lorenceau, 2012).

## 3.2 The History of Eye Tracking

The first qualitative descriptions of eye movements date back to the 18th century. The first data regarding eye movements were obtained by Porterfield at 1737, through introspection or observation using a mirror, telescope or peephole.

In the 19th century, Javal and Lamare observed the eye movements during reading and introduced the French word "*saccade*" for the abrupt movements of the eye. They used a mechanical coupling of the eyes and the ears using a rubber band to make the eye movements audible.

Initially, the eye tracking devices that produced objective and accurate data were highly invasive and uncomfortable. At the end of that century, Delabarre developed a system that used an eye cup with a lever extending do draw the eye movements on a surface covered with soot. The eye cup was attached directly to the surface of a sufficiently "cocainized eye" (usually Delabarre's eye) and had a hole in it through which he could see (Wade & Tatler, 2005).

In the beginning of the 20th century, appeared the first unobtrusive measurements. In 1901, Dodge and Cline used a photographic method and light reflections from the eye movements in horizontal direction only. Some years later, in 1905, Judd applied motion picture photography in eye movement recording. The invention of motion picture photography gave the possibility of frame-by-frame analysis of the eyes' motion and enabled quantitative research on a solid basis (Horsley *et at.*, 2013).

In 1939, Jung measured vertical and horizontal eye movements simultaneously, with electrodes applied on the skin close to the eyes. This method, known as Electrooculography (EOG), measures the electric field of the eyeball, which is a dipole and will be covered in the next chapter.

In the 1950s, Alfred L. Yarbus did important eye tracking research, having his book often been quoted (Yarbus, 1967). He showed that the task given to a subject has a very large influence on the eye movement and wrote about the relation between fixations and interest (Majaranta, 2009). Figure 3.4 is often referred to as evidence on how the task given to a person influences his or her eye movement. He also gave important contributions to the understanding of eye movements (see figures 3.3 and 3.10).

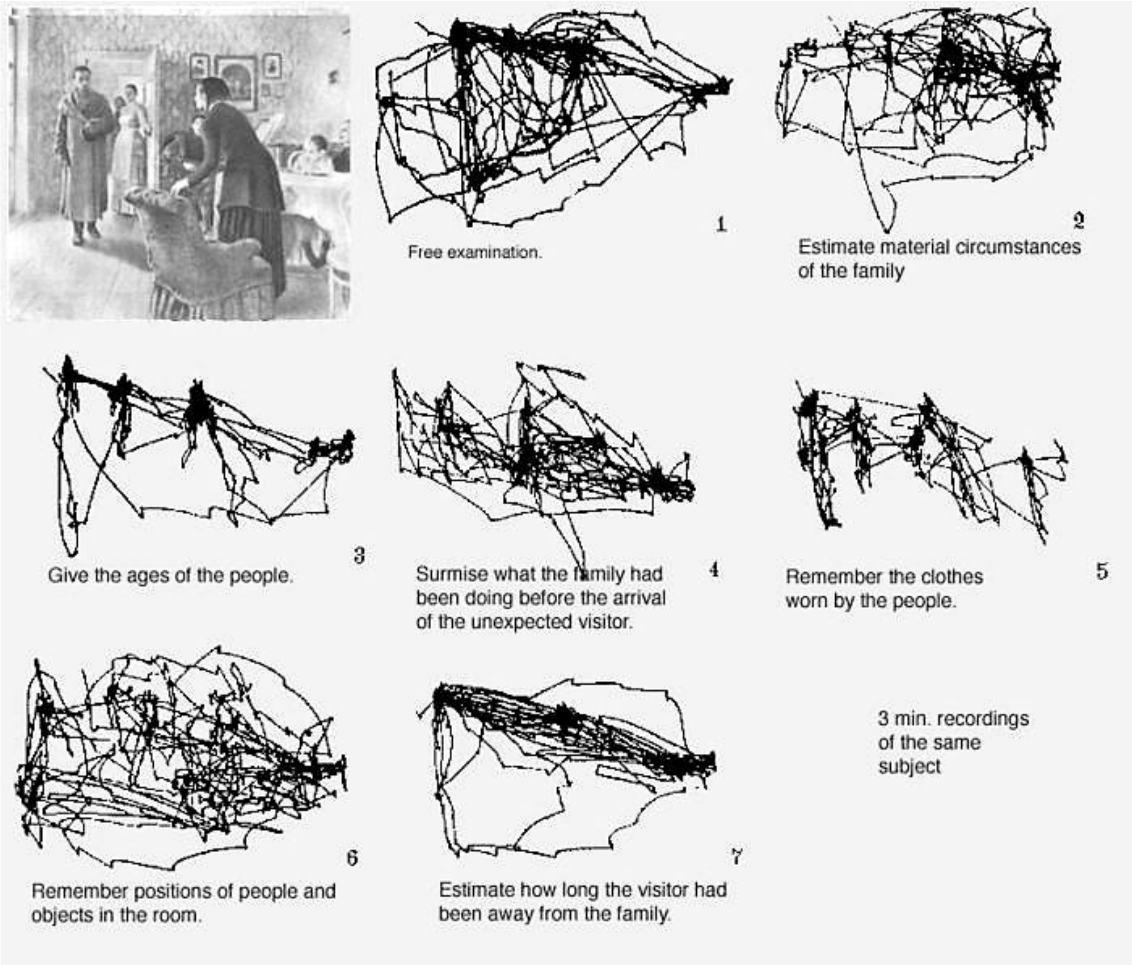


**Figure 3.4** – Study showing that eye movements are dependent on the person's task (Yarbus, 1967)

In the 1970s, there was great progress in eye-tracking technology. The eye trackers became less intrusive, provided better accuracy, and were able to dissociate eye from head's movements by multiple reflections from the eye (Cornsweet & Crane, 1973).

In the 1980s, the development of computing power made possible real-time eye tracking and this enabled the use of video-based eye trackers for human-computer interaction (Bolt, 1981). It was also the time of the emergence of assistive technology systems aimed directly at people with disabilities (Majaranta and Räihä, 2002).

These first systems were typically based on eye typing, where the user could produce text by using the focus of gaze as a means of input. One of the earliest eye typing systems, the Eye-Letter-Selector, detected eye movements with two phototransistors attached to eyeglass frames (Ten Kate *et al.*, 1979).

From the 1990s up to now, there has been a steady increase in the use of eye trackers. Tracking systems falling prices led to their wider use, typically in marketing research or usability studies (Majaranta, 2009).

## 3.3 Current Tracker Types

Eye trackers measure rotations of the eye as well as additional information, such as blink frequency and changes in pupil diameter. There are several ways to extract these features, but generally they fall into three main categories. One type requires the use of large contact lenses or in-eye magnetic coils that cover the cornea and sclera, with a metal coil embedded around the edge of the lens. Figure 3.5 shows a scleral coil contact lens, which was inserted in the eye of the subject. Eye movements are then measured by fluctuations in an electromagnetic field, when the metal coil moves along with the eyes. These measurements have provided extremely sensitive recordings of eye movement and are the method of choice for medical and psychological research to gain insight into human behaviour and perception (Duchowski, 2003).

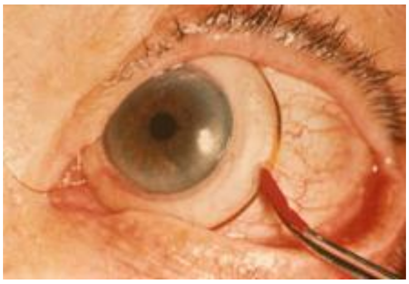

**Figure 3.5** – A scleral coil contact lens being inserted into a subject's eye (Kumar, 2007).

The second type, the already mentioned Electrooculography, relies on electrodes placed on the skin around the eye that measure its steady electric potential field. The method may seem impractical to the everyday life, but commercially available devices such as EagleEyes™ (figure 3.6) have revealed great success in augmentative and alternative communication area due to their high accuracy (Gips *et al.*, 1993). Another advantage is the ability to detect eye movements in total darkness and even when the eyes are closed, allowing the performance of sleep cognitive studies (Elbert, Lutzenberger, Rockstroh & Birbaumer, 1985).

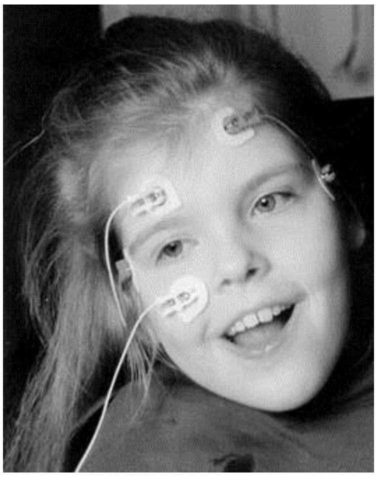

**Figure 3.6** – EOG approach – EagleEyes™ - for eye tracking measures the potential difference between eye muscles (Gips *et al.*, 1993).

These methods can be quite invasive and not appropriate for everyday life. The third and most popular variant uses video images, from which the eye position is extracted, and will be further analysed in the next section.

### 3.3.1 Video-based Eye Tracker Systems

This method is based on a video camera connected to a computer for real-time image processing. Two types of imaging approaches are commonly used in eye tracking: visible and infrared (IR) spectrum imaging. The light source is directed towards the eye and the camera tracks its reflection along with visible ocular features. These systems can have a remote approach, being completely unobtrusive, or a head-mounted approach, giving better accuracy (Al-Rahayfeh & Faezipour, 2013). Head-mounted eye trackers have been developed to fix the frame of reference for the eyes relative to the motion of the head (figure 3.7). Some head-mounted eye trackers provide higher accuracy and frame rate than remote eye trackers, since they are able to get a close up image of the eye by virtue of using the head-mounted camera.

**Figure 3.7** – A head mounted eye tracker which fixes the position of the camera relative to the motion of the head (Kumar, 2007).

The task of a video-based eye tracker is to estimate the direction of gaze from the pictures delivered by a video camera (Goldberg & Wichansky, 2003). These systems normally extract the direction of gaze by combining pupil detection with corneal reflection in order to obtain better accuracy.

There are two illumination methods to detect the pupil using IR lighting: the dark pupil and the bright pupil methods. Depending on the position of the light source, the pupil will become brighter or darker. When the light source is directly in line with the optical axis, the light reflects off the back of the retina and causes a bright pupil effect. This is essentially the same phenomenon that causes red-eye effect in flash photography. If the light source is offset from the optical axis, the reflection is projected away from the camera, making the pupil appear black.

Figure 3.8 represents the dark and bright pupil effects and the correspondent detected region (Al-Rahayfeh and Faezipour, 2013).

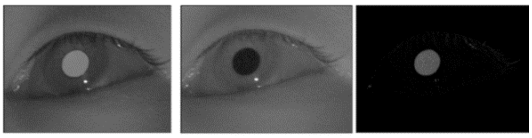

**Figure 3.8** – The bright and dark pupil effect and its detection and segmentation (Meunier, 2009).

The dark pupil method can become problematic for dark brown eyes, where the contrast between the brown iris and the black pupil is subtle. The bright pupil eye trackers require an illumination of the eye with IR light coming from the same direction as the view of the camera. Therefore, an IR LED has to be mounted inside or close to the camera, which requires mechanical effort (Nguyen, Wagner, Koons & Flickner, 2002).

Afterwards, a method for detection of the pupil in the camera image is required. Typically, edge detection is used to estimate the elliptical contour of the pupil (Schneider, 2004). Another algorithm for pupil-detection is the starburst algorithm (Dongheng, Winfield & Parkhurst, 2005). A more advanced alternative estimates the parameters of the elliptical shape of the pupil using Hough transform (Thomae, Plagwitz, Husar & Henning, 2002). Khairosfaizal and Nor'aini presented a straightforward eye tracking system based on the Circular Hough transform for eye detection applied to facial images (Khairosfaizal & Nor'aini, 2009). The system starts by detecting the face region, applying an existing face detection method, and then it searches for the eye based on its circular shape in a two-dimensional image.

Many eye trackers use a reflection on the cornea to estimate the direction of gaze, also known as Purkinje image. As the cornea has a nearly perfect spherical shape, a glint stays in the same position for any direction of gaze while the pupil moves and, thus, gives a basic eye and head position reference. As the radius of the cornea differs from person to person, this simple eye-tracking method needs calibration for each individual (Duchowski & Vertegaal, 2000). Figure 3.9 shows eye corneal reflection and pupil detection.

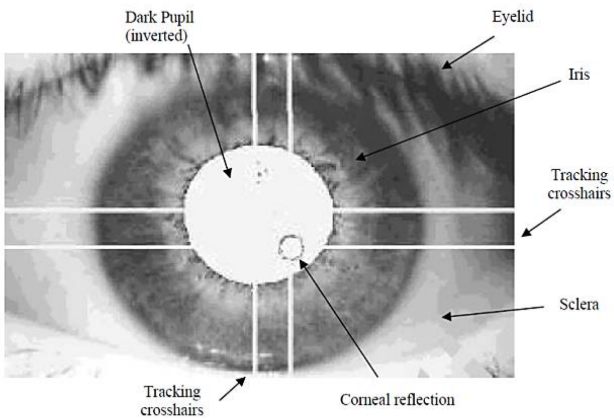


**Figure 3.9** – Video frame from a VOG system showing eye corneal reflection and pupil detection (Bates, 2006).

Yang *et al*. presented an algorithm based on the difference between the grey intensity of the pupil region and the iris region (Yang *et al.*, 2010). The image of the eye region is binarized, from which an estimate position of the pupil is detected. The exact position of the pupil is calculated from the vertical integral projection and the horizontal integral projection. The projection area contains the corneal glints and the pupil. The pixels representing refection points have the highest grey level among all pixels. To apply their gaze tracking method, the points of corneal refection must have known coordinates. However, the system uses hardware which adds limitations and inflexibility for pupil detection.

## 3.4 Eye Tracking as a Scientific Tool

Eye tracking has been used in the last century as a powerful tool for neuroscientific and physiological research (Duchowski, 2002). Eye movements can be related to cognitive processing and provide a window onto many aspects of cognition. Numerous studies demonstrated that eye movements are influenced by the physical and emotional human states. Recent investigations revealed that event-related responses to unpleasant images significantly inhibit the rate of microsaccade appearance (Kashihara *et al.*, 2014). Mental fatigue can also modulate the saccadic dynamics (Bahill & Stark, 1975) as well as microsaccadic and drift velocity (Stasi *et al.*, 2013). Furthermore, the size of the pupil is significantly related to the emotional stimulation which provides a cue of human emotion (Ekman *et al.*, 2008; Partala & Surakka, 2003).

Eye trackers are also a valuable tool for medical research and diagnostics to examine the function of the eyes, especially on people with eye injuries or brain damage that cause partial loss of vision. In these cases, eye tracking is used to monitor the success of physical rehabilitation.

The increasing sophistication and accessibility of eye tracking technologies have generated a great deal of interest in the market research and advertising testing. In general, commercial eye tracking studies function by presenting a target stimulus to a sample of consumers while an eye tracker is used to record the activity of the eye. The target can be a brand mark or a poster for an advertisement campaign. Portable eye trackers are also used in supermarket clients to find out which products people notice and how much influence the shape, colour or positioning of the product have on being noticed. Market research is the most valuable monetarily area in which eye trackers are used (Dongheng Li, 2006).

Another example is iris recognition, which is being widely used for biometric authentication (Pranith & Srikanth, 2010; Sundaram, Dhara, Chanda, 2011 & Daugman, 2009). Research is done by applying eye tracking methods in the vehicle industry with the aim of developing monitoring and assisting systems used in cars. For example, an alarm can warn a driver if he falls asleep while driving (Coetzer & Hancke, 2011; Sodhi *et al.*, 2002; Qiang & Yang, 2002).

## 3.5 Eye Tracking for Human-Computer Interaction

Human-computer interaction technology has been growing in an exponential manner up to today, giving rise to several different methods and types of interaction. Two types of human computer interfaces use eye movement measures: passive and active interfaces.

In passive interfaces, eye movement monitoring can provide an objective source of interface-evaluation that can enhance the design of interfaces.

For example, in the diagnosis field, information on eye movement can be used to improve speed and accuracy in x-rays diagnostic reading and ultimately save lives through early detection. Krupinski used eye-tracking to improve software for radiology image's analysis (Krupinski & Borah, 2006). Reading x-rays accurately is critical to an early and more precise detection, and can be taught by the way a radiologist examines an image. The locations to where the physician's gaze dwells might mean potential abnormalities and then more attention is needed to detect, extract and identify relevant features. Additionally, an eye movement recording represents a source of information to evaluate the interface user-friendliness, and allows the enhancement of the monitor display. When used as an evaluative tool in a study involving radiology residents, eye tracking improved overall diagnosis performance by 16 % (Krupinski & Borah, 2006).

Another field of commercial interest is usability research. With the rise of the World Wide Web as a commercial platform, the usability of web pages became an important topic. The behaviours can be analysed from measuring the user's eye movement while viewing web pages (Pan *et al.*, 2004).

Active interfaces allow users to explicitly use eye movements as an input mechanism for communication and control of an interface. For example, users can type on a virtual keyboard without using their hands, position a cursor with a simple look, or even use eye blinks to trigger mouse clicks.

The first obvious application of this capability is in augmentative and alternative communication field. In fact, the first real-time applications of eye-tracking in human-computer interaction addressed people with disabilities (Jacob & Karn 2003). Individuals with severe and profound impairments can use this technology to speak, send e-mails, browse the internet and perform other similar activities, using only their eyes. The increasing prominence of eye tracking in the assistive technology field is illustrated by the formation of Communication by Gaze Interaction (COGAIN) in 2004, an international consortium whose mandate is to promote the use of eye-tracking technology to individuals with severe motor disabilities (*COGAIN*, 2014). In Europe alone, the number of potential beneficiaries of eye tracking technology reaches several hundred thousand people, but, as yet, only a small number of these people are actually using eye control (Jordansen *et al.*, 2005).

With increasing accuracy and decreasing cost, eye tracking systems might be used to improve the traditional devices in the near future. Eye motion can enrich the communication experience with the computer, in conjunction with the keyboard and the mouse. Ultimately, some of the interaction techniques have the potential to replace or to constitute an alternative, which users may choose, depending upon their tasks abilities, preferences, or even momentary situation. Recent developments are applying this technology in more daily life situations. A shooter game where the user aims with the eyes and shoots with the mouse button, or an eye remote control that switches on a TV by continuous staring, are some of possible scenarios in the near future. Adding gaze information provides viable alternatives to perform everyday computer tasks, such as pointing and selection, scrolling and document navigation, application switching, password entry, zooming and much more (Drewes, 2010).

## 3.6 Input Eye Tracking Challenges

Using eye movements as a form of input seems a logical approach, since eyes are fast, thorough and provide a context of our actions. However, using eye motion has proven to be challenging for four main reasons: noise and accuracy issues, calibration and the "Midas Touch" problem.

### 3.6.1 Eye Movements Noise

As noted by Yarbus, eye movements are inherently noisy (Yarbus, 1967). In his pioneering work in the 1960's, he discovered that the eye movements are a combination of fixations and saccades, even when the subjects are asked to follow the outlines of a geometrical figures as smoothly as possible. Figure 3.14 shows an example taken from its experimental work.

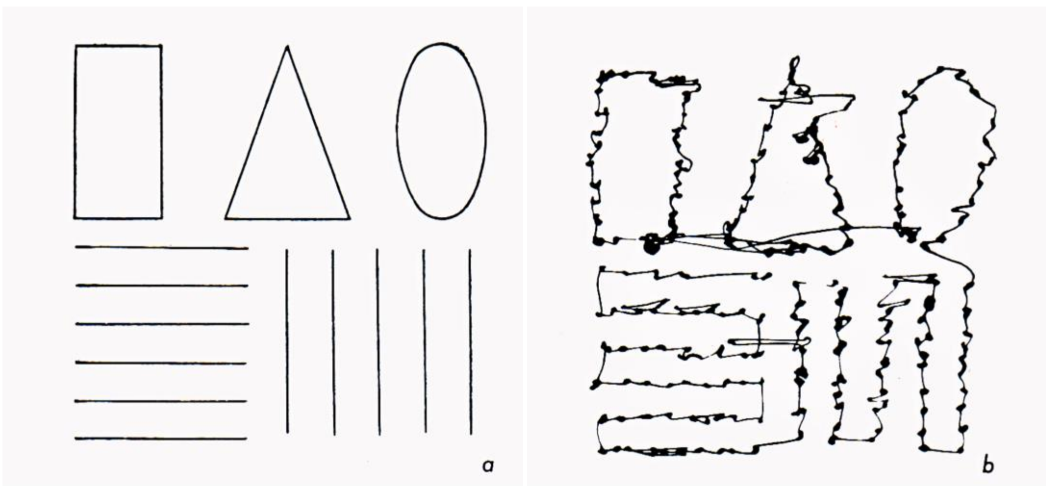


**Figure 3.10** Trace of eye movements when subjects are asked to follow the lines of the figures as smoothly as possible (Yarbus, 1967).

Additionally, as previously referred, even during fixations there are tremors and microsaccades that increase the noise of the obtained signal.

However, this issue can be solved by image analysis. The application of an appropriate filter can attenuate the noise of the movement, suppressing irregularities of the line shape. Special filters can also be applied in the case of user's eye movement disorders to smooth involuntary motions (Charlier *et al.*, 1997).

### 3.6.2 Accuracy Limitations

The eye's accuracy can be a limitation when the gaze is used as an input method in human-computer interaction. Many of the target objects in typical graphical user interfaces are smaller than the area of high-acuity vision. Even if eye trackers were perfectly accurate, the size of the fovea would restrict the practical accuracy of the system. Everything inside the foveal region can be seen in detail without moving the eyes, making it practically impossible to determine the exact pixel the user is looking at on the screen. Thus, gaze is not as accurate, as an input device, as a hand mouse (Sibert & Jacob, 2000). Therefore, eye's accuracy can be considered to fall between 1º and 2º. This angle corresponds to a region of 20 to 40 pixels on a 17-inch display with a resolution of 1024x768 pixel viewed from a distance of 50 cm.

This problem can be solved by increasing the size of the targets on the screen. Making on-screen objects much larger, makes them easier to hit and improves the performance of the eye. On the other hand, it hinders the presentation of complete keyboards due to lack of space on the screen. There must be a balance between the available space and the minimal required accuracy.

Current eye trackers achieve an accuracy of a 0.5º visual angle from the user. This is the equivalent of a region of approximately 10 pixels on a 17-inch display with a resolution of 1024x768 pixel viewed from a distance of 50 cm.

### 3.6.3 Calibration

Current video-based eye trackers require calibration so that they can be adjusted for a specific user. This is usually done by displaying a few points on the screen (usually nine equally spaced) and asking the user to fixate those points one at a time. The images of the eye are analysed and associated to screen coordinates. These main points are used to calculate any other point on-screen, via interpolation of the data. The accuracy of such systems is very much dependent on a successful calibration.

Over the time, it might be necessary a recalibration due to a drift effect on eye's original position. User's eyes may become drier, which alters their shape and reflective characteristics. User's posture changes leads to a different position/angle of the gaze. These issues have been studied, and some authors have proposed solutions.

Stampe and Reingold proposed a correction of the drift, by dynamically realigning the gaze position to the centre of any object selected while using the software (Stampe & Reingold, 1995). It is assumed that the user is looking at the centre of the object he wishes to select. If the point of gaze does not match the coordinates of the object's centre, an automatic drift correction is then applied.

The Tobii tracker uses data from both eyes to minimize drifting effects (Tobii, 2006). The system may continue with data from one eye, if the other is deteriorated. This enables long-lasting calibration with very little drifting and saves the user from continuous recalibration.

Nevertheless, some problems inherent to certain medical conditions deserve further in-depth studies in order to optimize the current systems, and to make them available to any physical condition. For example, thick eyeglass lenses or frames may cause extra reflections. When contact lenses are used, the reflection is obtained from the surface of the contact lens instead of the cornea. Both situations can cause problems if the lenses are displaced over time, causing degradation in tracking accuracy. This may be prevented or minimized through careful condition's setup, for example, by controlling illumination and camera position.

Finally, most eye trackers are powerless over severe involuntary head or eye movements. Certain medical conditions prevent successful calibration (Donegan *et al.*, 2005). If the calibration fails, some systems provide default calibration. Additionally, there are already some systems where no calibration is needed. A commercial Eye Contact Sensor called Eyebox2™ has this property (Dickie, Vertegaal, Sohn & Cheng, 2005). When looking directly at the combination of an eye tracker camera and an infrared LED, the glint of the corneal reflection appears in the centre of the pupil. The attention sensor only detects whether the glint is inside the pupil, to know whether an eye is looking at it or not.

### 3.6.4 The Midas Touch Problem

The primary function of the eyes is to enable vision. Therefore, using the eyes for computing input might result in conflicts. This effect is commonly referred to as the "Midas Touch" problem (Jacob, 1991).

Since the eyes are used for both perception and control, the system should be able to distinguish casual viewing from the desire to produce intentional commands. Misinterpretation by the interface can trigger unwanted actions. Distraction by moving or blinking might also cause conflicts.

The challenge is to design an intelligent interface to minimize false activations and to disambiguate the user's intention from the user's attention.

To overcome this limitation, it is common to combine some other modality for selection. If the person is able to produce some voluntary movement, a separate switch can be activated to select the item in focus, such as a blink, a sip, a wrinkling of the forehead, or even smiling or other muscle activity available to the user (Barreto *et al.*, 2000; Fono & Vertegaal, 2005; Huckauf & Urbina, 2008). Since people blink naturally several times per minute, an intentional blink needs to be longer than an automatic, i.e. longer than 300-400 ms. If the user is capable of moving only the eyes or has very limited motor control, the system must be able to separate casual viewing from intentional eye control. The most common solution is to use *dwell time*, i.e. prolonged gaze with duration longer than the normal fixation (about 200 ms), typically, 500-1000 ms. Fixations longer than 1000 ms are often broken by blinks or saccades or may be tiring to the eyes. Additionally, systems based on *dwell time* cause slower interaction that can be speed up for more able or experimented users. Therefore, the *dwell time* might be adjusted to the user (Majaranta *et al.*, 2006).

Another solution is to create a special selection area or an on-screen confirming button (Yamada & Fukuda, 1987; Ohno, 1998). For example, in the “quick glance” method developed by Ohno, selection is done by first fixating briefly on the desired command button and then confirming the selection by quick glance a selection area. These movements can be detected via electromyography or using the same video images, removing the need for additional switch equipment.

## 3.7 Eye Writing Systems

The basic methods for producing text by gaze have been researched since the early 1980s. Text entry methods can be categorized according to complexity of the input movement - eye switches, direct gaze pointing, gaze gestures, continuous pointing gestures and, more recently, smooth pursuit eye movement (Majaranta & Raiha, 2007; Lorenceau, 2012).

Eye switches, direct gaze pointing and smooth pursuit eye movements, whose performance will be evaluated based on the typing speed, are further characterized in this section. Typing speed is measured in words per minute (wpm) where a word is any sequence of five characters, including letters, spaces, punctuation, and others (MacKenzie, 2003).

For a complete list of the commercially available eye writing systems, consult COGAIN network (COGAIN, 2014).

### 3.7.1 Eye Switches

In some physical conditions or health states, people may have difficulties in fixating or moving the eyes in one direction, for example, in the lock-in syndrome (Donegan *et al.*, 2005; Chapman, 1991). In such cases, voluntary eye blinks or winks can be used as a binary switch (Grauman *et al.*, 2003). This is the most rudimentary method but, unfortunately, is the only applicable in some conditions.

A famous example is the memoir "Le Scaphandre et le Papillon", written by Jean-Dominique Bauby (figure 3.15). In 1995, the French editor of the Elle magazine, suffered a stroke causing a locked-in syndrome. He wrote an entire book describing the feelings of this condition by just blinking his left eyelid. Locked-in his own body, the writer defines his body as useless but still painful - "my hands, lying curled on the yellow sheets, are hurting, although I can't tell if they are burning hot or ice cold". (Bauby, 1997). A transcriber repeatedly recited the alphabet frequency-ordered in the French language (E, S, A, R, I, N, T, U, L …), until Bauby blinked to choose the desired letter.

The average writing rate was one word every 2 minutes (0,5 wpm). The book took about 10 months and 200 000 blinks to write but become a number one bestseller across Europe (The New York Times, 1997).

**Figure 3.11** - Photograph of Jean-Dominique Bauby paralyzed, dictating his last book "Le Scaphandre et le Papillon" one letter at a time by eye movements to Claude Mendibil before dying of heart failure (Mallon, 1997).

### 3.7.2 Direct Gaze Pointing

The most common way of eye typing is direct pointing by looking at the desired letter. A typical setup has an on-screen keyboard with a static layout. An external eye tracker monitors the eye movement and a specific software is responsible for the post processing.

The user starts to focus the desired letter by looking at one of the keys of the virtual keyboard. The system gives feedback on the selected letter by jittering, highlighting the item or by moving a cursor over the key in focus, among several other ways. Once focus is achieved, the item can be selected via different cues, such as a blink, a wink, or even a wrinkle or any other muscle activity. For severely disable people, *dwell time* is often the best and the only selection method. If the user keeps focusing a key long enough, then the key is selected. The period time is typically between 500-1000 ms, but some software programs offer the possibility of adjusting this time to the user. The *dwell time* determines the typing speed, typically below 10 wpm. Experienced users may require considerably shorter *dwell times* as low as 200-300 ms, which, naturally, increases the text entry rate, achieving 20 wpm. The selected letter appears in the text field, often located above the keyboard. The system may also give feedback on the successful selection by speaking out the letter or playing a "click" sound. Different feedback methods can be applied to support the writing task. This feedback should be considered carefully. If the user needs to switch the point of gaze from the virtual keyboard to the typed text field, to review the previously written text, the writing process will become very time consuming and, therefore, inefficient.

Typically, the keyboard has a QWERTY layout design, where all characters are visible and letters can be directly pointed at and selected. Alternately, the keys and controls can be organized hierarchically or by most common letters of certain language. Figure 3.17 shows a typical QWERTY on-screen keyboard, while figure 3.16 displays an alternative ABCD keyboard.

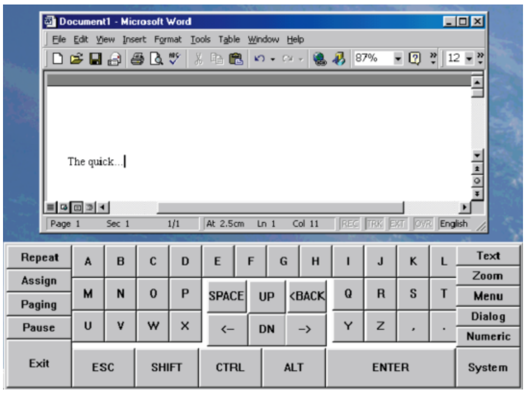


**Figure 3.12** - EC Key, an example of a gaze-driven keyboard using an ABCD structure (Istance *et al.*, 1996).

Special techniques such as automatic word prediction can be used to speed up the text entry, with constantly changing and adapting keyboard layouts. It is the fastest eye typing method, with an average rate of 15 wpm for an expert user. Figure 3.17 shows an example of on-screen keyboard, highlighting the most probable next letter.

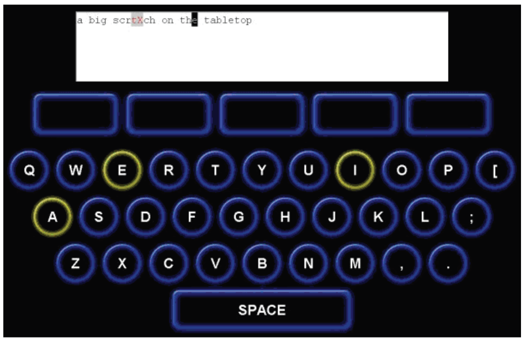


**Figure 3.13** - Letter prediction is used to highlight the next probable letters on the keyboard. The empty boxes between the text input field and letter keys are filled with predicted words if word prediction is enabled (MacKenzie & Zhang, 2008).

## 3.7.3 Smooth Pursuit Eye Movements

Learning to control smooth pursuit movement is the latest method of cursive writing with eyes. In contrast to the current and aforementioned systems, in which it is only possible to type letters and words with the aid of virtual keyboards, Jean Lorenceau has developed a novel method, which enables people to draw and write by using free eye movements (Lorenceau, 2012). Although the ocular system has a high precision when it comes to follow a moving subject, it is not capable of performing smooth and regular movements, when drawing a voluntary trajectory. Indeed, in front of a static background, eyes only perform saccades showing a very rudimentary muscle control (Lisberger *et al.*, 1987). Using a visual illusion called reverse-phi, it is possible to control smooth pursuit eye movements and perform regular trajectories. The device takes advantage of this effect by displaying several hundred disks, whose contrast varies over time on a screen. While moving the eyes over this flickering background, the users feel that the disks move with the displacement of their eyes (figure 3.18).

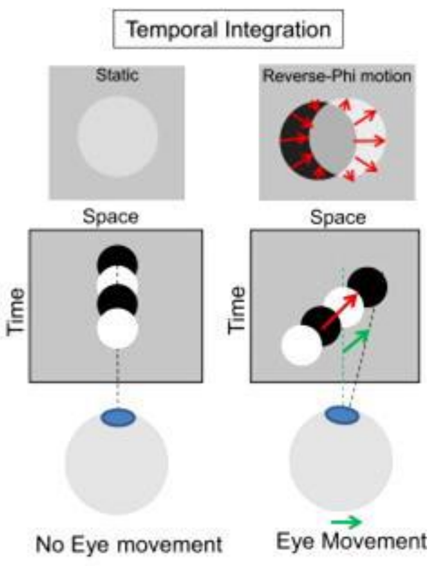


**Figure 3.14** - Retinal spatiotemporal luminance profile with static and moving eyes. An eye movement produces a reverse-phi stimulus on the retina, generating a positive feedback to the pursuit system. The resulting directionally broadband motion flow (red arrows) provides a perceptual substrate to orient pursuit and control eye trajectory. (Lorenceau, 2012).

Since the human eye is capable of following, with precision, moving objects, the illusory movement of the disks, induced by the movement of the eyes, acts as a feedback effect that allows users to perform smooth trajectories. An eye tracker records the movement of user's eye and a software tracks the position of the pupil over time and compiles them, processing the designed letters by segmentation of the ocular trace (figure 3.19).

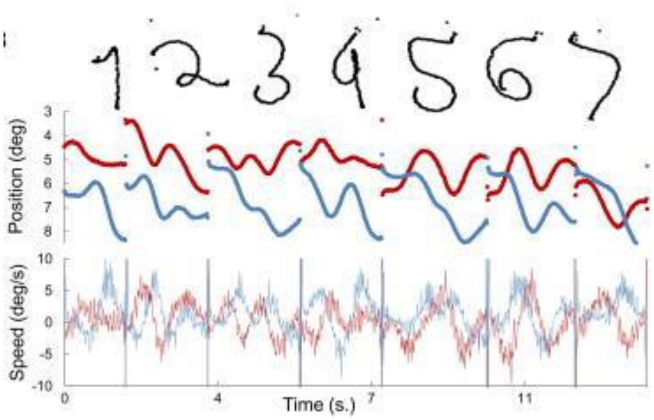


**Figure 3.15** - Examples of eye-generated digits after segmentation. Vertical (blue) and horizontal (red) eye position and eye velocity are also shown (Lorenceau, 2012).

Thereafter, a computational model based on Bayesian inference can translate the information through a probabilistic method of character recognition (Diard, Rynik & Lorenceau, 2013).

The training process to control smooth eye muscle movements typically consists of 4 to 6 training sessions that last for about 30 minutes, in different days. The subjects first learn to perceive the reverse-phi movement and then to progressively use it as support for drawing figures. In the beginning, it can be a tiring task, but well-trained individuals create automatisms that facilitate writing, reaching an eye writing speed almost equal to the one obtained with hand writing. Even if the throughput is lower with this method than with virtual keyboard, it can allow motor impaired people to continue expressing themselves in an emotionally rich manner, despite their motor disability.

## 3.8 The Eye Tribe™

The Eye Tribe™ tracker is a low-cost and small device created by "The Eye Tribe"™ Company and it was used for the studies presented in this dissertation. In 2013, the Danish start-up launched their eye tracking technology. This device, shown in figure 3.10, has broken the record for smallest eye tracker device in the world, measuring 20×1.9×1.9 cm (The Eye Tribe™, 2014).

**Figure 3.16** – The small dimensions of The Eye Tribe™ (20 x 1.9 x 1.9 cm) (The Eye Tribe™, 2014).

Currently, the company is selling the eye tracker for $99 along with a software development kit using C++, C# and Java programming platforms for developers to start incorporating the technology into their apps.

The Eye Tribe™ tracker starts by detecting the face region, applying a face detection method, and then it searches for the eyes based on the bright pupil detection method. A high resolution sensor combined with the IR illumination system provides the conditions for track the tiny movements of the pupils with high precision while maintaining a wide field of view. A pair of (x, y) eye gaze coordinates are calculated with respect to the screen with an average accuracy of around 0.5 to 1º of visual angle. Assuming the user sits approximately 60 cm away from the screen/tracker, this accuracy corresponds to an on-screen average error of 0.5 to 1 cm. The eye tracker can be mounted in a tripod to be used in a desktop or in a specific support when used on a tablet. The summary of the tracker features is displayed in the table 3.1.

**Table 3.1** — Technologic specifications of The Eye Tribe™ tracker (The Eye Tribe™, 2014).

| | |
|---|---|
| **Sampling rate** | 30 Hz and 60 Hz mode |
| **Accuracy** | 0.5° – 1° |
| **Spatial Resolution** | 0.1° (RMS) |
| **Latency** | < 20 ms at 60 Hz |
| **Calibration** | 9, 12 or 16 points |
| **Operating range** | 45 cm – 75 cm |
| **Tracking area** | 40 cm x 30 cm at 65 cm distance (30 Hz) |
| **Screen sizes** | Up to 24” |
| **API/SDK** | C++, C# and Java |
| **Data output** | Binocular gaze data |
| **Dimensions (W/H/D)** | 20 x 1.9 x 1.9 cm |
| **Weight** | 70 g |
| **Connection** | USB 3.0 Superspeed |

In order to track the user’s eye movements and calculate the on-screen gaze coordinates, the tracker must be placed below the screen and pointing at the user. The user needs to be located within the Tracker’s *trackbox*. The *trackbox* is defined as the volume in space where the user can theoretically be tracked by the system. The size of the *trackbox* depends on the frame rate, with a higher frame rate offering a smaller *trackbox*.

**Figure 3.17** – On the left, the right position of The Eye Tribe™ related to the screen and the user. The tracker must be placed below the screen and pointing at the user. On the right, the tracking area known as *trackbox*, which is defined as the volume in space where the user can theoretically be tracked by the system (The Eye Tribe™, 2014).

Prior to using an eye tracker, the user needs to undergo a calibration process. As it was already mentioned, the eye tracking software needs to model the eye characteristics of each person in order to estimate gaze accurately. A typical user calibration process of The Eye Tribe™ takes approximately 20 seconds to complete. It consists in a circular target that is displayed at different locations of the screen on a blank background during around 2 seconds each. The user needs to look at the target as this is displayed on the screen (figure 3.12). Once all the calibration targets have been displayed on the screen the calibration process is completed. A star rating evaluation indicates if the process was successfully finished. A minimum of 9 calibration locations covering most of the screen is recommended. Using more locations (e.g. 12 or 16) will improve the accuracy of the gaze coordinates computed by the system.


**Figure 3.18** – On the left, The Eye Tribe™ user interface. There is a feedback that indicates the user if he is in the right position and therefore the eyes are correctly detected. On the right, the calibration process and the evaluation window above indicating if the process was successfully finished (The Eye Tribe™, 2014).

Gaze coordinates correspond to the point on the screen that the user is currently looking at and are defined as pixels in a top-left oriented 2D coordinate system (figure 3.13 on the left). They are available in both raw and smoothed forms for the left and right eye. Additionally, pupil coordinates, pupil size and information about the state of the eye tracking process are also given. Pupil coordinates are the position of a tracked person's pupil relative to the tracker sensor and are defined in normalized relative values (figure 3.13 on the right).


**Figure 3.19** On the left, gaze coordinates in pixels in top-left oriented 2D coordinates system. On the right, pupil coordinates in normalized values relative to tracker device (The Eye Tribe™, 2014).

At this stage, The Eye Tribe™ tracker is not bundled with any applications for common use, and it is intended only for software developers. Therefore, it is necessary to develop the script according to the specific purpose.

## 3.9 Concluding Remarks

The general survey of eye tracking systems allowed to get acquainted with important aspects of these systems, namely the different formats and methodologies that are offered but also the current limitations to take into account.

The “Midas Touch” problem, as well as calibration, noise and accuracy issues are still challenges to overcome in this field. Depending on the specific problem and need, efforts should be made in order to find the best solution to each problem.

Regarding the available eye-writing systems, three strategies have been analysed. Eye switches are the most basic but do not provide effectiveness in writing speed. Cursive writing with smooth pursuit eye movements, although allowing great freedom of expression, requires several training sessions. Finally, keyboards controlled by direct gaze pointing seem to be the best option in this case. It does not require prior learning and it is available for immediate use. That was thereby the solution of choice for this project.

By reviewing the wide-ranging technologies and solutions, it can be concluded that the approach that best fits the problem and need might be a remote video-based eye tracker. It should also be small, light and practical but ensuring a good accuracy and high data transfer rate. The Eye Tribe™, chosen for the performance of the present study, presents all these features.

# Chapter 4

# The Eye Communication System

The previous survey of the actual problems and needs as well as the review of the current eye tracking systems were the basis for developing an adequate eye communication system for nonspeaking patients.

The introduction of the medical device is expected to promote non-verbal communication with patients, to improve the understanding of their wishes, and act in anticipation, in order to define the user's requirements and to reduce the anxiety at ICU. Meetings with the hospital team were carried out in order to optimize the entire system and fulfil the patients' needs. The research team will remain in contact with the medical personnel for continuous optimization and validation of the overall system and future projects.

This chapter describes the methodology that has been adopted for the creation of the medical device, the usability tests on healthy subjects to verify its effectiveness and the following steps of device testing in patients.

## 4.1 The Equipment

Once the device will be applied in a hospital environment, ergonomics is extremely important. The hardware was thought to be lightweight and of practical usage.

The eye tracker used in this project was the already mentioned The Eye Tribe™. This device has several advantages regarding its size, weight and low-cost. The use of a laptop allows conceiving a mobile, practical and economic solution, applicable in the hospital's everyday life. To connect the eye tracker, it is necessary that the computer features an USB 3.0 port, usually found on the most recent computers.

The main screen is used for controlling the eye tracker and additional features, while a second screen displays the communication GUI. The technical research team continues working to find more ergonomic solutions using a single screen or even a tablet.


**Figure 4.1** – The eye communication system consists on the eye tracker on the bottom to record eyes' position, one screen on the left for commands control and one screen on the right providing the GUI for eye communication.

## 4.2 The Application to get gaze data

The tracker software is based upon an open API (Application Programming Interface) design that allows client applications to communicate with the underlying Tracker Server to get gaze data. The communication relies on JSON (JavaScript Object Notation) messages asynchronously exchanged via TCP (Transmission Control Protocol) Sockets.

C++ was the language of choice to develop a script in Microsoft Visual C++ Express that extracts the average (x, y) coordinates and pupil size from both eyes. These coordinates are read by JEDA software (Jean Lorenceau © 2014) and used as an input peripheral. The JEDA software allows the creation of graphical user interfaces for menus navigation, which will be explained later.

The Eye Tribe™ company provides an example of script that defines a TCP connection through the inclusion of Boost libraries (Boost, 2014). Although initially this methodology has been successful, it was incompatible when integrated in the current system. Therefore, the Windows Sockets API was used to establish a direct connection between the client implementation (JEDA) and the tracker server (The Eye Tribe™).

The script developed for this purpose is described, in short, below.

It starts by including the library `winsock.h` that contains the tools and functions needed for the connection. It then initializes the winsock by the function `WSAStartup()` that specifies the sock version and where to stock the data. The TCP socket is created by the function `socket()` and connected to local host, on the port used by The Eye Tribe™ for communication. The connection is established by the function `connect()` and the exchange of data with the eye tracker is initialized. The client program sends and receives data with the functions `send()` and `recv()`.

A running tracker server with no connected clients will be in a dormant state and will not send data to clients. The Tracker Server will be implicitly running as long as there are clients connected and sending stay-alive messages, aka. heartbeats, within a server-defined interval.

Thus it is also necessary to start and read a heartbeat thread in order to guarantee that the connection is kept.

To disconnect, a client may explicitly close its socket connection or simply stop sending heartbeats. When the connection is finished, it is necessary to shut down the winsock and for that purpose, the function `WSACleanup()` is applied.

## 4.3 The Graphical User Interface

Episodes of communication between patients and paramedics are usually brief and consist of predetermined questions or reinsurance.

Herein, the communication is established through a graphical interface that depicts buttons with icons illustrative of patients' needs. The selection of the "needs" to be included was defined according to the clinicians' requests (see the nine priority concerns in 2.6 section) and by adaptation from advices of health professionals associated to the project.

By gaze fixation, the icons start to jitter and if kept for a pre-defined duration (*dwell time*), the current option is selected. Each button has a symbolic picture and colour accompanied by a descriptive text. The combination of image, colour and text gives a clear interpretation and thus adapted to different types and ages of patients. Buttons have uniform size and position to be easier for users to "hit" with their gaze.

After selecting the basic need, a following sub-menu allows patients to specify their wishes. It was attempted not to create long chains of menus, once those can be confusing and ambiguous to the patient. Hence, it was implemented a hierarchy of 2-level menus, but one with 3 levels for better description. At the end of the chain, no other menu is opened and the communication is made by vibration of the observed word. Hence, it is always necessary to have some caregiver around to follow the navigation and read the jittering word.

All menus and sub-menus provide a *Retour* button to return to the previous menu.

According to hospital statistical sources, there are just 0.36% of foreign patients at Pitié-Salpêtrière Hospital (APHP, 2014). Therefore, the entire GUI was developed in French, the native language, so as to be accessible to the greatest number of patients.

All the images were selected from free web sources or created from draft. Both types were then modified by drawing software.

In addition to the communication by sequential menus, the program can have a free communication mode which allows the patient to answer to yes/no questions or even select the option *CLAVIER* to use a keyboard by visual contact.

In case of emergency or wanting to call an assistant, the patient has an SOS button that triggers an audible alarm.

All options, layout, colours and figures of icons can be changed to adapt to specific situations and contexts.

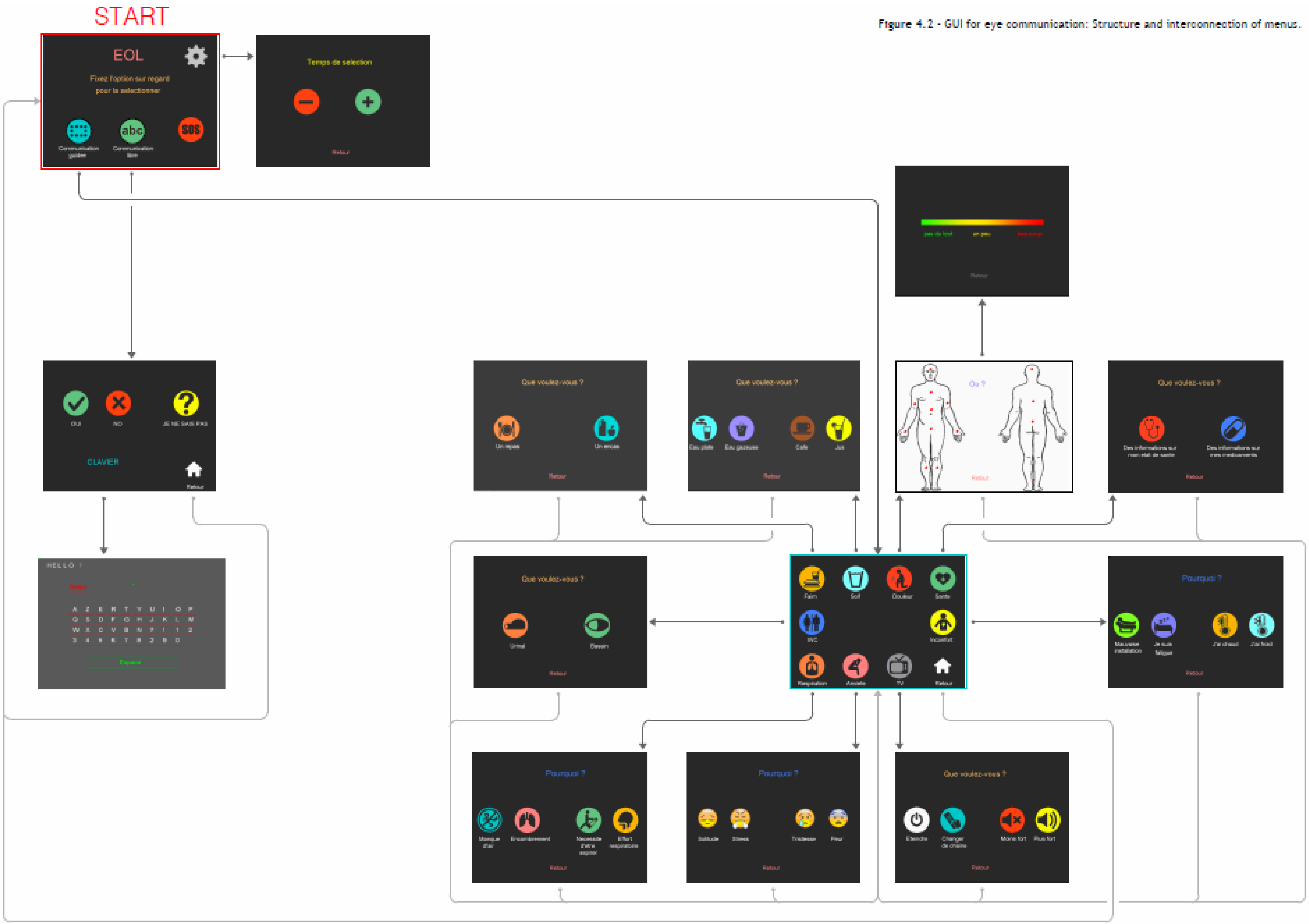


Figure 4.2 - GUI for eye communication: Structure and interconnection of menus.

The *dwell time* can be set by the user. New users generally start around 1 second or slightly greater. With practice, most people will want to reduce their *dwell time* so that they can access familiar content faster. As seen before, the setting of this parameter brings the patient greater autonomy.

The GUI was also adapted to patients with ALS (amyotrophic lateral sclerosis). Modifications are shown in Annex 2. Its test in this population is under process with pending results.

This program was created entirely using JEDA (Jean Lorenceau © 2014) software within the EOL project. The general structure for menus navigation is presented in figure 4.2 and explained in detail below.

The PNEUMO program will open on the Welcome Page displayed in figure 4.3.

In the first menu there is a short explanation of the program's functioning and the following four buttons whose actions will be explained hereafter:

- Guided communication
- Free communication
- SOS
- Preferences.


**Figure 4.3** - GUI for eye communication: Welcome page.

**Guided communication**

By selecting the button Guided Communication, the Welcome Page is replaced by a new page (figure 4.4) containing 9 buttons representative of needs/intentions namely: hunger *(Faim)*, thirst *(Soif)*, pain *(Douleur)*, health *(Santé)*, bathroom *(WC)*, discomfort *(Inconfort)*, breathing *(Respiration)*, anxiety *(Anxiété)* and television *(TV)*.

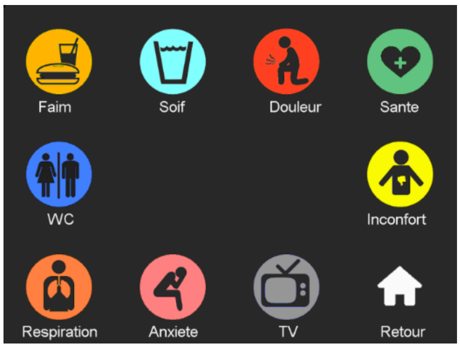


**Figure 4.4** - GUI for eye communication: Guided communication page.

Each button will open a new page in order to specify the desired option as it will be described below. By selecting the *Retour* button the menu returns to the Welcome Page.

**Hunger**


**Figure 4.5** - GUI for eye communication: Hunger page

The Hunger page only provides two buttons: meal (*Un repas*) or snack (*Un encas*). The limited selection is due to constraints of patients' health and hospital resources.

**Thirst**


**Figure 4.6** - GUI for eye communication: Thirst page.

For the same reasons, the selection of the drink is limited to the available and recommended drinks for patients at ICU, namely mineral water (*Eau plate*), sparkling water (*Eau gazeuse*), coffee (*Café*) or juice (*Jus*).

**Pain**

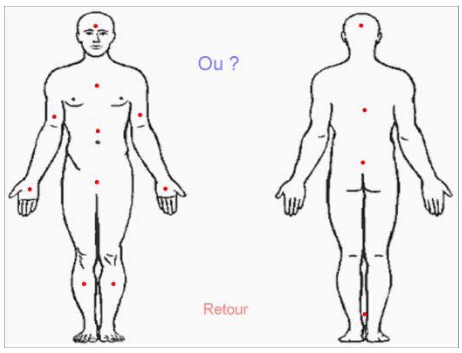


**Figure 4.7** - GUI for eye communication: Pain page.

By selecting the *Douleur* button, the patient is asked to locate the pain source by observing the red spots on the human figure. When observed, the respective point starts to jitter to inform the caregiver its location.

After reporting the pain location, a third sub-menu appears, displaying an intensity scale ruler. The pain level is informed by observation of the corresponding scale region / colour which will make jitter the closest word. The range of choice is limited to 3 levels: none *(Pas du tout)*, moderate *(Un peu)* and severe *(Beaucoup)*.

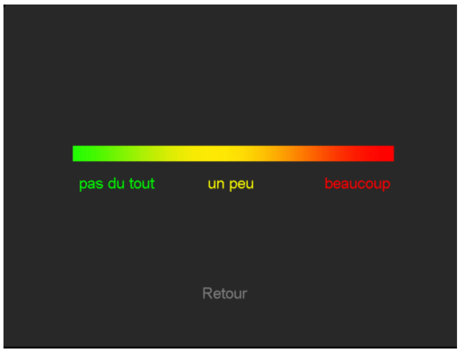


**Figure 4.8** – GUI for eye communication: Pain level page.

### Health

The users select the *Santé* button when intending to receive information about their health's state *(état de santé)* or pharmaceutical prescriptions *(medicaments)*.

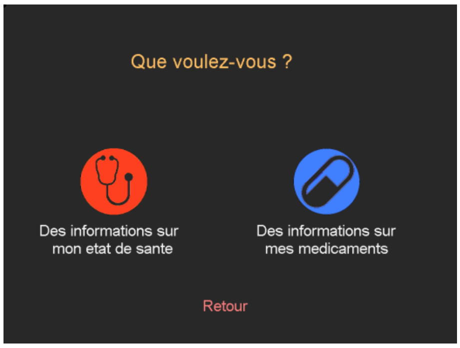


**Figure 4.9** – GUI for eye communication: Health page.

### WC

The WC page allows the patient to ask for objects related to personal's hygiene namely the urinal and the basin.


**Figure 4.10** – GUI for eye communication: WC page.

## Discomfort

This menu intends to minimize the patient's discomfort. Thus, the corresponding button is selected in case of feeling tired *(Je suis fatigué)*, hot *(J'ai chaud)* or cold *(J'ai froid)* or needing mobility assistance *(Mauvaise installation)*.


**Figure 4.11** - GUI for eye communication: Discomfort page.

## Breathing

This menu allows reporting eventual pulmonary problems that might occur after an operation or treatment. Therefore, following the specialists recommendations, there are available the options: lack of air *(Manque d'air)*, congestion *(Encombrement)*, need to be aspired *(Nécéssité d'etre aspiré)* and respiratory effort *(Effort respiratoire)*.


**Figure 4.12** - GUI for eye communication: Breathing page.

## Anxiety

This menu tries to minimize the frustration felt by patients who cannot communicate their anxiety. The wide range of emotions was reduced to four elementary options: loneliness *(Solitude)*, stress *(Stress)*, sadness *(Tristesse)* and fear *(Peur)*.


**Figure 4.13** - GUI for eye communication: Anxiety page.

### TV

Once the patient is alone for many hours, the television is a major concern. This menu allows the patient to say if he wants to change the channel *(Changer de chaine)*, the volume *(Moins fort / Plus fort)* or even turn off the TV *(Éteindre)*.


**Figure 4.14** - GUI for eye communication: TV page.

### Free communication

Once in the Welcome Page, the patient can chose a free communication by selecting the respective button and opening the page of figure 4.15. The patient has then the possibility to answer questions posed by the nursing staff selecting *"OUI"* (yes), *"NO"* (no) and *"JE NE SAIS PAS"* (I do not know). If patients wishe to clarify their answer they can choose the *"CLAVIER"* and to write freely.


**Figure 4.15** - GUI for eye communication: Free communication page.

Between the aforementioned methodologies for eye writing (see section 3.7), the direct gaze point strategy using a QWERTY keyboard was chosen, since it does not require previous learning and its usage is fast and universal.

### Keyboard

In this case, the typical QWERTY keyboard was adapted to French speakers, and so keys are disposed in an AZERTY structure. This allows patient to write any word by simply look at each key. After a *dwell time*, the letter is selected and appears at the top of the screen. There are also the options *"Espace"* to make a space and *"Reset"* to delete.


**Figure 4.16** - GUI for eye communication: Keyboard page.

SOS

By observing this icon, an alarm is triggered for 17 seconds.

**Preferences**

In this menu, the patient can set the *dwell time* for icons' selection. The "+" provides a longer duration while the "-" a shorter one.


**Figure 4.17** – GUI for eye communication: Preferences page.

In the future, ludic menus can be added to play games or even make music with eyes.

**Piano**

An example of a ludic piano is shown in figure 4.18. By staring at each key, the corresponding note is played loud.

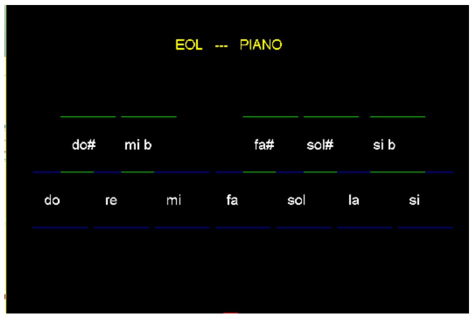


**Figure 4.18** - GUI for eye communication: example of a Piano page.

## 4.4 Addressing the Input Challenges

Certain strategists attempted to address the reported input eye tracking challenges.

The noise coming from the restless movement of the eyes was atenuated by an average of the (x, y) coordinates. The Eye Tribe™ gives the information regarding the eye position in both raw and smoothed forms. In the present system, it was used the average data that filters microsaccades, eliminating some of the movement's noise.

As seen before, eye's accuracy is limited to the size of foveal region which corresponds to 1° to 2°. In order to increase the accuracy of the system's response, we created icons with large dimensions. Each icon has a circular dimension of 150 x 150 pixel which corresponds to 5° visual angle from the user, on a 17-inch display with a resolution of 1024 x 768 pixel viewed from a distance of 50 cm. Under each image there is an explanatory text, resulting in a sensitive area of 200 x 200 pixel (approximately 7° visual angle). The spacing between icons was also considered. Although variable, depending on the number of icons per page, efforts were made to ensure that the spacing between two consecutive icons would be greater than 100 pixels. Large and spaced targets minimize the choice uncertainty caused by fixation difficulty and provide a comfortable navigation through the menus.

In order to solve the "Midas Touch" problem, certain strategies were useful. First, in each page it was attempted to leave a central empty space with no action or information. Some studies demonstrated that in free viewing of static images, gaze fixations are biased toward the screen centre (Tseng *et al.*, 2009; Smith & Mital, 2013). For that reason, the empty space in the centre allows people to have a general overview without selection. Secondly, it was applied the already mentioned *dwell time* solution. Once a normal fixation has an average period of 200 ms (Poole *et al.*, 2005), we need to use a gaze with longer duration. By default, it is set a *dwell time* of 1000 ms but this parameter can be adjusted by the user.

Each icon starts to jitter when under fixation, as a feedback signal. Other solutions could have been applied as a feedback signal such as icon's highlighting or color change. Furthermore, outside the selection areas a small red point follows the eye gaze so that people know exactly where the fixation is all the time. The usefulness of this feature is controversial, since it can be considered as a distraction source. However, in most cases it was helpful to control the gaze movement. Moreover, this point has an additional function on the need for recalibration that will be further explained.

Since The Eye Tribe™ is not head-mounted, calibration is an important process. Once set, very sudden movement of the head/body will lead to bias in the data. However, in this case, unobtrusiveness was a crucial factor in the context in which it was inserted. This factor was clogged with a tracking of both eyes minimizing drifting effects. A remote eye tracking system constantly updates the user's position, however, it is difficult to avoid deviations on the calibration derived from marked changes of the initial position. Our assumption is that, in this case, the gaze-locked point also helps the user himself to detect a shift in calibration. Ultimately, aware that the point does not coincide exactly to where he is looking at, the user can try to make an empirical fit to match the point with the desired icon. This can be a temporary solution until a new recalibration. However, recalibration might not be a critical issue, since patients are normally bedridden and with reduced mobility.

These conjectures may be confirmed in future, during the usability tests in healthy subjects and in patients at ICU.

## 4.5 Usability Tests

In order to evaluate the developed graphical user interface, usability tests were performed in four healthy subjects. Their eye movements were recorded while observing six pages of the GUI, in order to know exactly their eye's behaviour. After a free navigation, a questionnaire was conducted to obtain user's feedback about functional and aesthetic aspects of the GUI. The GUI was displayed on a 1024 x 768 resolution screen located at about 50 cm from the subject (figure 4.19).

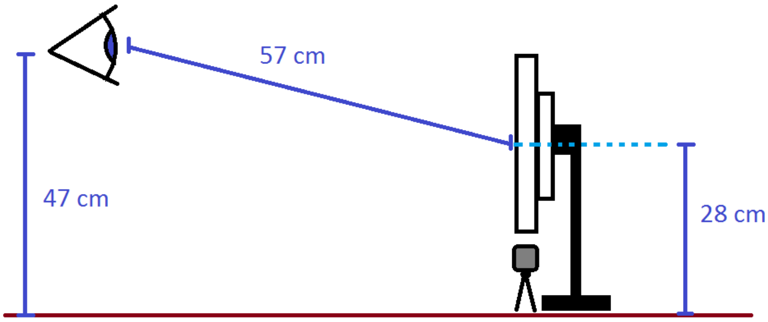


**Figure 4.19** - Eye communication system installation for the usability tests.

The data acquisition was performed using Windows 7 Pro ©2009 at a 64 bits / Dell Precision T5600 with a processor Intel Xeon CPU E5-2609 at 2.40GHz (2 processors) and a memory RAM of 32.0 GB. The movements of both eyes were recorded with a remote infrared video-based eye tracker (The Eye Tribe™ Tracker Server, version 0.9.36) via JEDA (Jean Lorenceau © 2014) with a recording frame rate of 60 Hz. Calibration was done using 9 points with a period of fixation of 2 seconds each. The eye traces were analysed offline using Matlab (Matlab R2013b, Version 8.2.0701) and consisted on:

- No smoothing
- Average data normalization
- Manually offset correction in both axis
- Data superimposition with corresponding image

Data was also analysed using Excel (Microsoft Excel 2010, Version: 14.0.7128.5000 32 bits), using the same procedures.

The four participants were young adults (24-32 years old, 2 females and 2 males, 3 French-native and 1 Chinese-native), familiar with laboratory experiments.

The distance between the observer and the display influences the observational angle. Shorter distances to the screen allow higher eye movement angles to scan the display's area. However, the eye tracker used in this study has an operating range of 45 - 75 cm for its best performance. In order to measure the influence of the distance to the screen we considered that the eye is positioned in the middle line as shown in figure 4.20. Analysing the extreme distances of the operating range when observing an icon of 150x150 pixel it can be concluded that the angle's variation is about 2°.

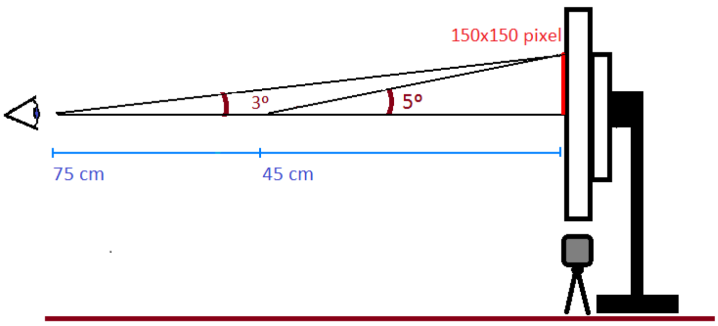


**Figure 4.20** - Variation of the observational angle depending on the distance to the screen when observing an icon with 150x150 pixel area.

Participants were initially asked to explore an image from the GUI in a freely way (Welcome Page – see figure 4.3). The recording was made during 2500 frames (about 42 seconds). Afterwards, participants were asked to observe another five pages from the GUI following certain indications. In the Guided Communication page (see figure 4.4) participants were asked to successively observe each icon for 3 seconds while in the Hunger page (see figure 4.5), participants were asked to focus only one of the icons. In order to simulate real situations, in the Pain page (see figure 4.7) participants were suggested to locate: a right leg cramp, a migraine headache and a stomach ache / colic. Then they were asked to quantify a pain using the Pain level page (see figure 4.8) and following the indications: mild pain, great pain and unbearable pain. In the last part, participants were asked to write a word using the keyboard (see figure 4.16). The suggested words were namely “HELLO”, “MAISON”, “AVION” and “HOUSE”. The results will be analysed and discussed afterwards.

The final questionnaire consisted on 12 questions with YES-NO answer and an open question for comments and opinions (questions are shown in Annex 1). The current survey was written in French and translated into English, in order to be available to all participants.

## 4.6 The Device Assessment at the Hospital

According to the European guidelines for medical devices classification, this system is included in Class I since is non-invasive, and does not have physical contact with the patient (European Commission - DG Health and Consumer, 2014).

The device will be tested at the department of Pulmonology and Medical Intensive Care Unit, Pr T. Similowski ER10 - University Pierre and Marie Curie, Groupe Hospitalier Pitié-Salpêtrière (Paris, France). The study will be promoted by ADOREPS *(Organisation de la Recherche en Pneumologie et sur le Sommeil)* and it will be initiated after a favourable opinion of the CPP *(Commité de Protection des Personnes)*.

The main objective of the medical team study is to evaluate the impact of the new tool on the quality of non-verbal communication in ICU intubated patients. The specific objectives of this study are the following:

- to evaluate the benefit of this tool in the detection of discomfort sources at ICU. The clinician will evaluate the origin and the cause of the discomfort experienced by the patients. Additionally, the physician will perform an assessment of the patient's nervousness and anxiety level, due to communication difficulties.

- to evaluate the benefit of detecting the intensity of the discomfort. Once detected the discomfort source, this communication tool will allow quantifying discomfort using a visual scale.

- to evaluate the effectiveness of this tool on reducing the sources of discomfort. This study intends to determine whether the presence of the tested communication tool allows acting on earlier discomfort detection and thus meeting the patient wishes more efficiently.

As secondary objectives, it will be evaluated the nurse ease in understanding the patient's discomfort and the workload represented by the tool for the medical personnel.

The assessment of the medical device will consist on an observational study in patients hospitalized for acute respiratory failure requiring mechanical ventilation by endotracheal tube. This study compares two strategies: non-verbal communication of intubated patient at ICU, using the eye tracking, and non-verbal communication, by the use of current techniques of the service, namely communication boards.

The medical team will evaluate the nine discomfort items that were considered as priority concerns at ICU (see 2.6 section) namely: pain, anxiety, lack of air, excessive respiratory effort, need to be aspired, desire to be informed about their health state, bad installation and thirst.

### 4.6.1 Patients Inclusion Criteria

Patients will be randomly included in the study if they meet the following criteria:

- Adult patients hospitalized in the ICU;
- Mechanical ventilation through an endotracheal tube or tracheostomy orotracheal;
- Remaining estimated mechanical ventilation > 48 hours of mechanical ventilation provided for ventilator weaning;
- Conscious and communicating patients, defined by criteria score ATICE (Adaptation To Intensive Care Environment) (Karampela *et al.*, 2002). This assessment is defined by the ability to answer the following five commands:

    1) Open / close eyes,
    2) Open mouth and sticking out the tongue,
    3) Watch the examiner,
    4) Nod,
    5) Lift eyebrows after the examiner count until 5.

- No confusion, defined by criteria score CAM-ICU (Confusion Assessment Method for the Intensive Care Unit) (Ely *et al.*, 2001). This is a current score for the diagnosis of delirium that consists in a sequence of questions and tasks. The patient needs to be able to follow a sequence of letters and squeeze the examiner's hand when detecting the letter "A". If not able to do it, the examiner will evaluate the level of disorganized thinking by asking the following questions:

    1) Will a stone float on water?
    2) Are there fish in the sea?
    3) Does one pound weigh more than two?
    4) Can you use a hammer to pound a nail?

Patients will not be included in the study if one of the following criteria is present:

– Minor patients;

- Protected adults, whose mental faculties are impaired thereby making it impossible for them to attend to their own welfare;

- Pregnant women;

- Patients with difficulties in communicating, namely with impaired visual or auditory visual or auditory acuity;

- Patients with insufficient knowledge of the French language;

- Patients diagnosed with psychiatric disorders;

- Patients diagnosed with cognitive disorders.

### 4.6.2 Assessment's method

Patients that were selected from the group that met the inclusion criteria will be exposed successively to two strategies in a random order namely:

- 24 hours with the eye tracker communication tool;
- 24 hours without the tool, using the non-verbal communication methods available in the service.

The patient will have access to the communication tool 3 times per day. This process will be monitored by a nurse that will evaluate the communication process with the patient according to the criteria described below.

- Time spent to communicate.
- The overall content of the communication range.
- Method of communication used: eye tracking medical device, head shaking, lip reading, communication board.
- Graduated scale of the additional workload.
- Graduated scale of the difficulties in understanding the patient.

Similarly, the doctor will evaluate twice a day (during the morning and night visit) the communication with the patient according to the criteria detailed below.

- Graduated scale of the patient's nervousness related to communication difficulties.
- Graduated scale for the patient's fear related to communication difficulties.
- Rating Scale of difficulties' type:
    - Communication difficulties on communication in general
    - Communication difficulties on the physical needs
    - Communication difficulties for care.

### 4.6.3 Regulatory compliance

The test consists on a non-interventional study that does not amend the diagnostic practices or the therapeutic management of patients. Indeed, the communication with the patient addressing his discomfort is an essential step in the management of patients during ICU stay. This study is therefore an integral part of clinical practice and is routinely performed in the ICU concerned in this study. Tests will be initiated and conducted by the clinician and the nurse in charge of the patient. Their implementation will be consistent with current practices in the participating services.

Moreover, the employed methods of measurement are completely painless and atraumatic. The ventilatory parameters collected will not require any invasive procedure. Measurement of blood gases to allow the specialist in charge to weaning from respiratory support and to better adjust the parameters of mechanical ventilation will be performed routinely.

The study involves no risk to the subjects.

# Chapter 5

# Results and Discussion

In order to evaluate the developed eye communication system, usability tests were performed in four healthy subjects followed by a survey to assess the user's experience.

This chapter contains the results together with the discussion. This assessment may confirm its functionality and whether the strategies followed to solve the challenges inherent to eye tracking were successful. This is an important preliminary phase before starting the tests on patients and to verify if the developed interface suits the needs both on a functional and aesthetic level.

## 5.1 Usability Evaluation using Eye Tracking

Participants were positioned inside the eye tracker's *trackbox* (see section 3.8), between 50 and 57 cm from the display. This variation caused a difference on the observation angle of about 0.5° which was not considered since it did not influence the participant's performance.

Data concerning eye movements was obtained with The Eye Tribe™ and analysed with MatLab or Excel software. Calibration evaluation provided by the eye tracker was higher than 3/5 for all the subjects.

The results are disposed in a xy graphic which corresponds to the 1024 x 768 resolution screen. The origin (0,0) is located at the top-left corner of the display. The eye position in each frame is represented by a point with different colours in contrast to the background. Data was superimposed on the original images of the GUI pages.

### 5.1.1 Free Viewing

Participants were asked to explore one of the pages of the GUI in a freely way and the results are presented in figure 5.1. The rational of this test was to infer whether, in free viewing of static images, gaze fixations are biased toward the screen centre (Tseng *et al.*, 2009; Smith & Mital, 2013). This essay will also show how people explore a static image and eventually reveal unpredictable behaviours.

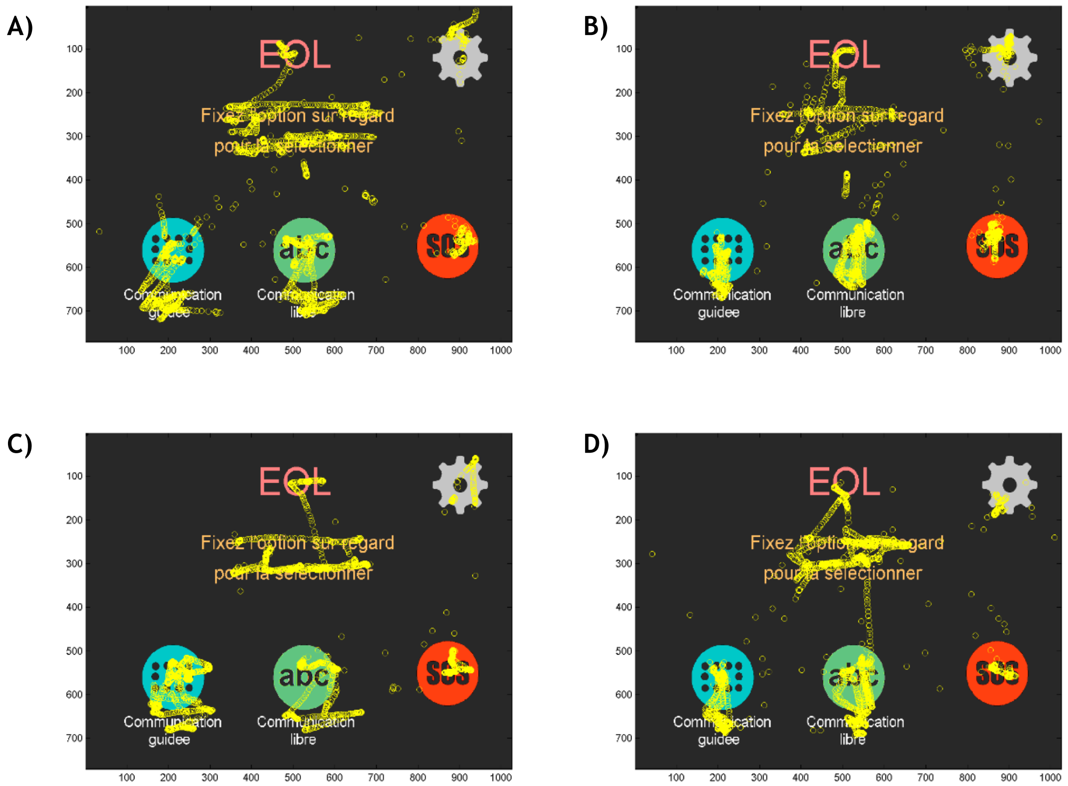


**Figure 5.1** – Free exploration of the Welcome page from the GUI for eye communication. User's eye movements were recorded with The Eye Tribe™ in 60 Hz mode, during 2500 frames. Data of the eye's coordinates are represented by yellow circles. A), B), C) and D) represent subjects AL, DA, JM and LC respectively.

When analysing the data generated by the user's eye movements during free exploration, it can be seen that people spend more time reading the text at the centre and then explore the buttons around. The SOS and Preferences buttons are the ones which gaze dwells for shorter period once it is where there is less information.

The positions of the eye on time were analysed separately and are represented in figure 5.2. The coordinates x and y on each frame are represented on blue and connected by a continuous line. The first twenty coordinates of each run are coloured in red and line-connected as well.

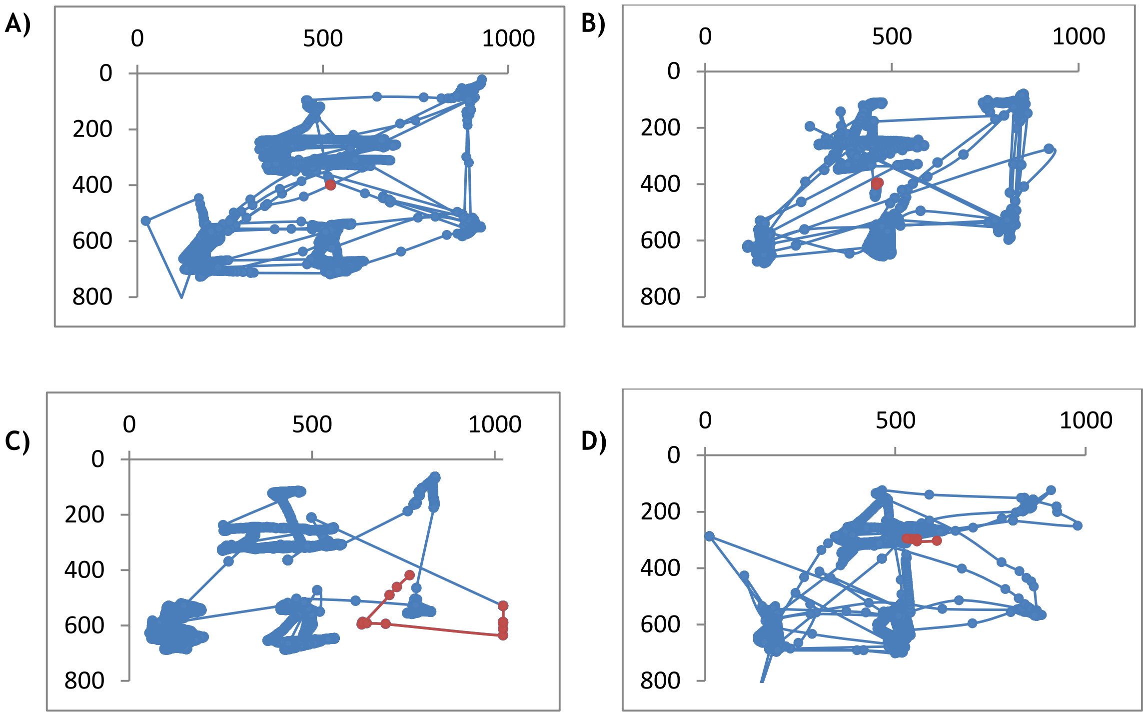


**Figure 5.2** – Free exploration of the Welcome page from the GUI for eye communication. Records were performed with The Eye Tribe™ in 60 Hz mode, during 2500 frames. Data of the eye's coordinates are represented by blue points. The first twenty coordinates (x,y) are depicted in red. A), B), C) and D) represent subjects AL, DA, JM and LC respectively.

For all participants, it can be seen that the initial eye's position are located on the centre of the picture. One subject (JM) has a sudden movement in the beginning while the other 3 remain the first 20 frames (0.33 s) located at the same place. In the same subject the coordinates at the x axis were truncated at 1024, which corresponds to the screen limit. Higher values mean that the participant is observing outside the screen. As seen in the literature, people have tendency to initiate observation on the centre of the screen during free viewing of static images. These results confirm that information and support our strategy of leaving empty spaces in the centre of the menus to avoid unintended selections.

The presence of the continuous line connecting the eye's position reveal the different exploration behaviour across the subjects. While the subject JM concentrates his gaze only once at each object of the page for a certain time, the others observe each object quickly but several times. This fact can be due to a familiarization to eye movement's experiments that granted him greater ocular control. However, the other 3 subjects are also familiarized with that kind of experiments and did not show that behaviour. A superficial examination showed that this participant practices the highest level of martial arts that may influence the eye's dynamics. As seen before (section 3.1.2), eye dynamics may be influenced by the activity performed by the person. Nevertheless these are suppositions that needed more data and deeply investigation to validate.

### 5.1.2 Sequential Observation

After free viewing, participants were asked to successively observe each icon of the Guided communication page for 3 seconds. The purpose of this essay was to analyse if the icons are sufficiently spaced out. Results are shown in figure 5.3.

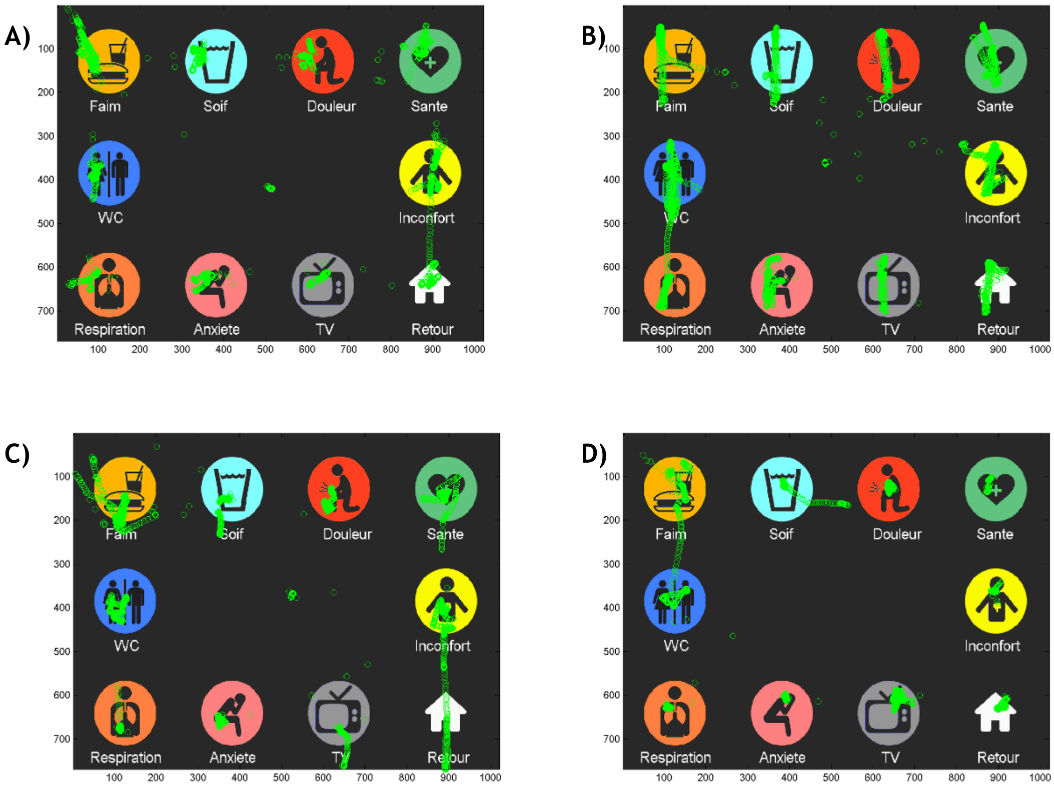


**Figure 5.3** – Successive observation of the icons presented on the Guided communication page from the GUI for eye communication. User's eye movements were recorded with The Eye Tribe™ in 60 Hz mode, during 2500 frames. Data of the eye's coordinates are represented by green circles. A), B), C) and D) represent subjects AL, DA, JM and LC respectively.

When asked to observe each button one at a time, it can be concluded that people's gaze is concentrated at the centre of each icon and do not exceeds significantly its boundaries. The observation focus does not overlap each other showing that the spacing between them is sufficient. Moreover, this proves that the size of each icon is big enough and easy to select. These data demonstrate that even in the page with greater number of icons, the button's selection is made unambiguously.

## 5.1.3 Icon Fixation

In this case, participants were asked to fixate on only one icon. This essay aims to ascertain whether the size of each icon is appropriate. Results are presented in figure 5.4.

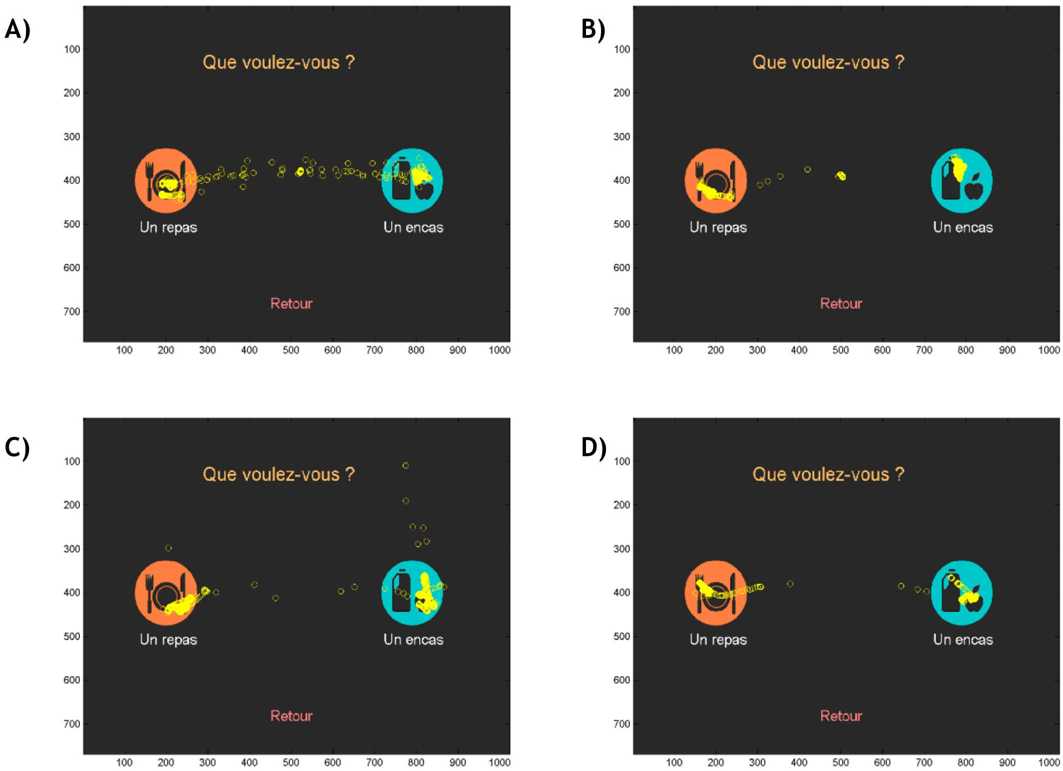


**Figure 5.4** – Observation of one icon from the Hunger page from the GUI for eye communication. User's eye movements were recorded with The Eye Tribe™ in 60 Hz mode, during 1000 frames. Data of the eye's coordinates are represented by yellow circles. A), B), C) and D) represent subjects AL, DA, JM and LC respectively.

Analysing the previous results, it can be seen that people concentrate their gaze inside the button's limiting circle. None of the subjects exceeds the boundaries when asked to maintain the gaze. This test confirms that the size of each button provides a comfortable navigation.

## 5.1.4 Pain Localization

Participants were then asked to locate simulated symptoms namely a right leg cramp, a migraine headache and a stomach ache / colic. This task was performed to confirm whether the available number of points in the human body at the Pain menu and their distribution are appropriate. Moreover, it was intended to examine the distance between points and check if there is overlapping of the points' region. Results are presented in figure 5.5.

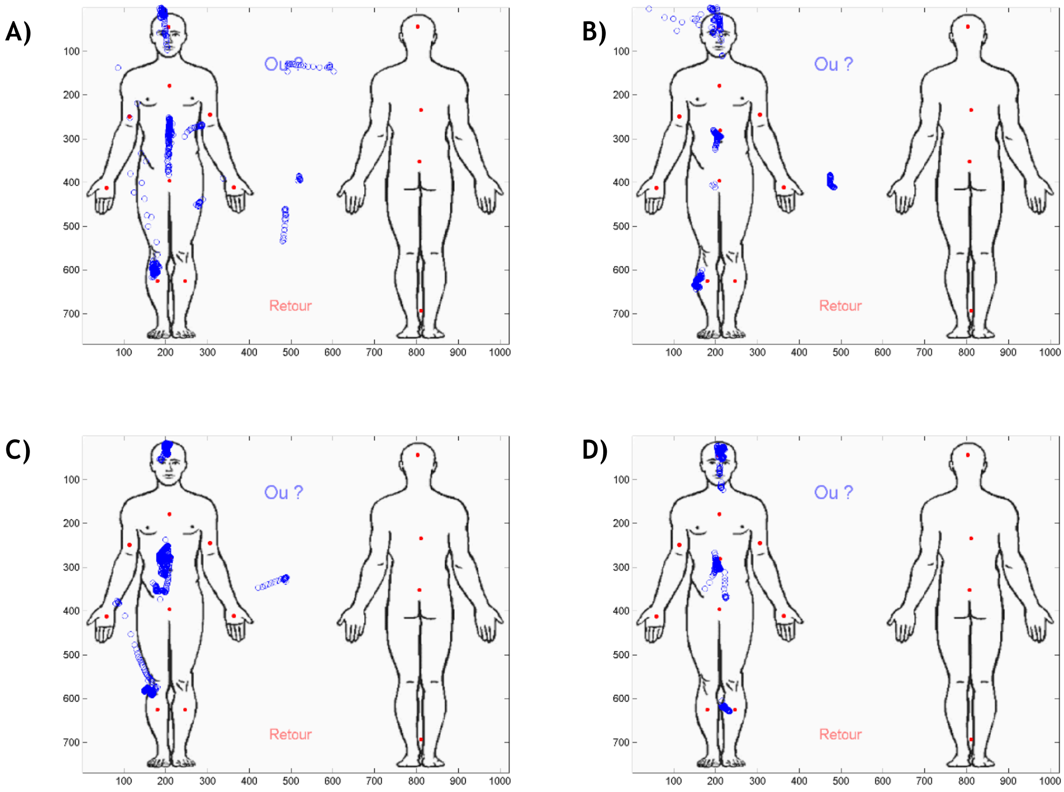


**Figure 5.5** – Observation of the corresponding point of specific questions from the Pain page from the GUI for eye communication. Participants were asked to locate: a right leg cramp, a migraine headache and a stomach ache / colic. User's eye movements were recorded with The Eye Tribe™ in 60 Hz mode, during 1000 frames. Data of the eye's coordinates are represented by blue circles. A), B), C) and D) represent subjects AL, DA, JM and LC respectively.

When asked to localize specific symptoms, participants should fixate the points on the right leg, head and stomach respectively. All the participants showed to be perfectly able to do it, with the exception of the subject LC that observed the left leg instead of the right one. That was due to the mirror effect that may cause confusion. This page could include the indications Right/Left *(Droit/Gauche)* next to the body to avoid future misleading.

There is no overlapping of the point's regions meaning that they are sufficiently spaced.

In general, the system is poorly discriminatory since it has a reduced number of points distributed by the human body. On the head for example, there is only one point on the front side and another one on the backside. This fact does not allow distinguishing, for example, a toothache from an earache. As seen from the results, the participants observe the entire region of the head to report a migraine. Once the head has reduced dimensions in this image (approximately 100x100 pixel), eye's accuracy is not enough to indicate exclusively the forehead. To better express precise pains, an extra menu containing a larger image of the head could have been added. However this system only serves as an initial screening of symptoms and, therefore, simplicity is a priority.

### 5.1.5 Pain Quantification

Using the Pain level page, participants were asked to report a mild pain, a great pain and an unbearable pain. Analogous to the previous test, the aim was to access the discriminatory power of the pain's level scale. Results are presented in figure 5.6.

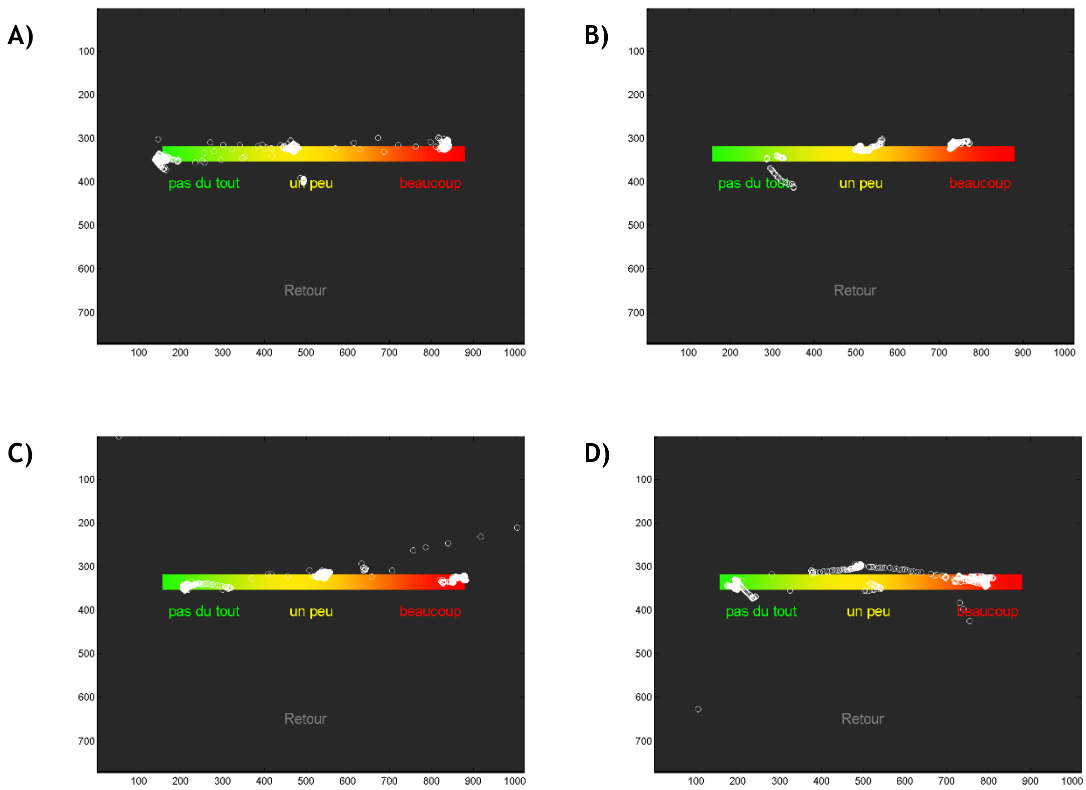


**Figure 5.6** – Observation of the region/word corresponding to specific questions addressing the Pain level page of the GUI for eye communication. Participants were asked to locate: mild pain, great pain and unbearable pain. User's eye movements were recorded with The Eye Tribe™ in 60 Hz mode, during 1000 frames. Data of the eye's coordinates are represented by white circles. A), B), C) and D) represent subjects AL, DA, JM and LC respectively.

Participants had to classify a pain using the pain's scale. Although this request could have a subjective component, all participants responded as expected. Subjects began by looking at the green region that corresponds to the green word *Pas du tout* to report a mild pain. After participants looked at the yellow and finally at the red zone, corresponding to moderate and severe pain, in order to report a great and an unbearable pain, respectively.

As in the previous results, the range of choice is limited. In this case, there are only 3 levels to describe the pain. The eye tracking technique is always conditioned by the inaccuracy of human eye and therefore is not possible to offer a wide range of choice. Moreover, the inferential level achieved here is sufficient for the requirements it sets.

### 5.1.6 Eye Writing with the Keyboard

Using the keyboard, participants were asked to write “HOUSE”, “AVION”, “MAISON” and “HELLO”. The purpose of this test was to inspect the efficiency of the keyboard. The results are provided in figure 5.7.

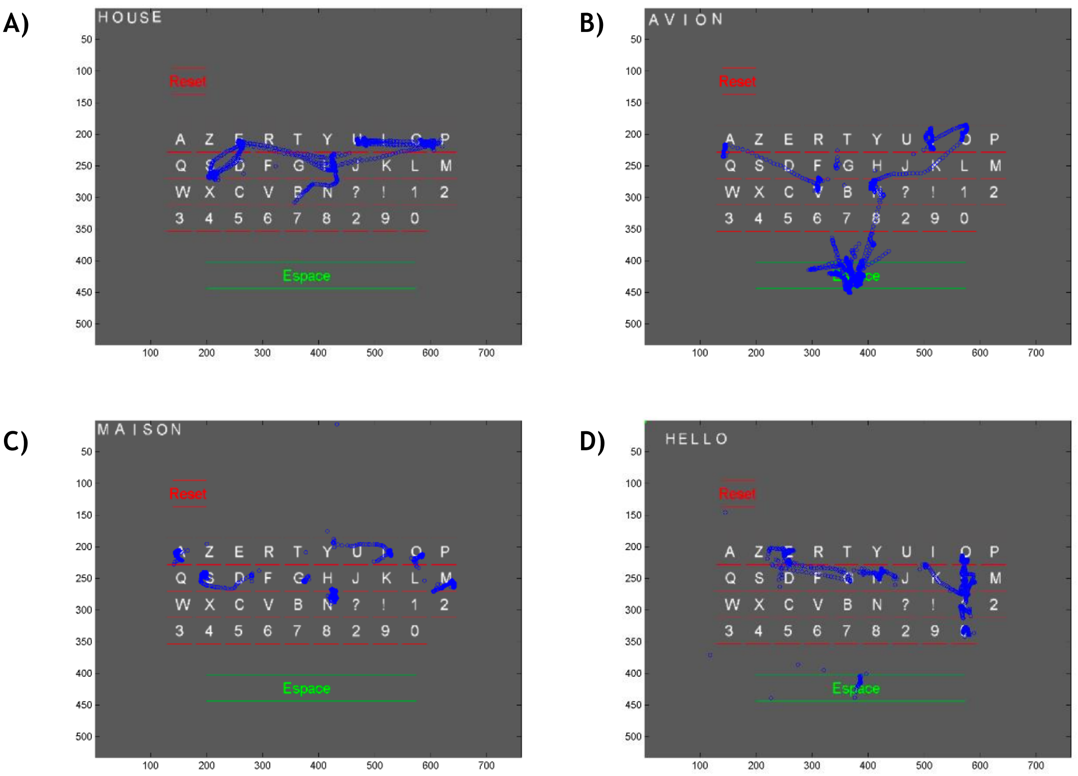


**Figure 5.7** – Subjects observation of the keys from the keyboard page of the GUI for eye communication. Participants were asked to write “HOUSE”, “AVION”, “MAISON” and “HELLO” respectively. User’s eye movements were recorded with The Eye Tribe™ in 60 Hz mode, during 2500 frames. Data of the eye’s coordinates are represented by blue circles. A), B), C) and D) represent subjects AL, DA, JM and LC respectively.

As it can be seen, all subjects achieved to write the demanded word. Despite the small size of each key and the reduced space between them, participants were successful in their task. Between fixations, participants gazed upon other keys but did not remain there time enough to select them involuntarily.

All the words but one were composed by 5 letters. Writing speed was not analysed, since that was not relevant for the usability evaluation. However, previous studies shown that, in eye writing using QWERTY keyboards, the writing rate is about 15 wps.

## 5.2 Navigation Survey

Analysing the questionnaires conducted after free navigation on the menus, it can be concluded that the overall user's experience was very positive.

The current survey was written in French and translated into English, which permitted a response rate of 100%.

As for the functional aspect, all participants affirm that it is easy to navigate through menus using the eyes and that the GUI's structure is not confusing, i.e., there are not too many sub-menus.

None of the users needed to adjust the *dwell time* and, therefore, all of them navigated using the default time of 1000 ms. All participants claim no difficulties in maintaining gaze to select options. None felt the system to be too sensitive, namely by accidently selecting unintended options. These last two facts confirm the proper setting of the default time.

As for the red gaze-locked point, 3 in 4 participants confirm that it is useful while 1 affirms to be a distraction source. The same user has detected that, during navigation, the point no longer coincided exactly with the position on the screen to where he was looking at. In this case, the point helped him to detect a need for recalibration. With the remaining 3 users this situation did not occur, discarding the need for a new calibration. This situation confirms our previous assumption that the gaze-locked point is helpful on the detection of recalibration's need.

All users confirmed that the feedback – jitter – is helpful to know the probable selection and to navigate in the GUI.

Regarding the graphical aspect, users claim that the developed GUI has an attractive and appealing design. All respondents confirm that the texts are legible and that the combination of the text with the image has a clear understanding. The Chinese participant had just classified the size of the text and the contribution of the image once he is not French speaking and therefore did not understand the menus' information content. Among the 4 participants, 3 consider that the colour associated to each icon helps in communication. On the other hand, half of the users think that the images are infant-like particularly on the Anxiety page.

The comments and suggestions left in the open part showed that the ruler to express pain level is poorly scaled. Generally, respondents consider the system to be playful and easy to operate.

## 5.3 Concluding Remarks

All participants were familiar with experiences of this nature which may cause a bias in the results. Their activities can have an influence on the ocular dynamics, namely on the ease to fixate an icon to select it or in the ocular behaviour. We can exclude the influence on the fixation time for selection once the *dwell time* may be adjustable. Besides, the default value has been set based on the values presented in literature and therefore adequate to normal subjects. Other bias that may be due to the participant's activities were difficult to discriminate.

The range of distances between the participants (50 – 57 cm) was irrelevant on the variation of the observational angle.

Recalling the issues in which we focused more efforts (see section 4.4) we can conclude that, for the 4 participants:

- the noise coming from the eye's movement was prior filtered by The Eye Tribe™ ;
- the buttons are large allowing an easy and effective selection;
- the buttons are sufficiently spaced avoiding confusion when selecting an option;
- default *dwell time* is adequate to common use;
- empty space in the middle of each page avoids premature selections;
- the jitter is a helpful feedback;
- the gaze-locked point is not considered in most of the cases as a distraction source;
- the gaze-locked point is helpful on detecting a calibration bias;
- recalibration is not required in most of normal uses;
- the design is appealing and user friendly.

On the other hand some weak points were detected that could be improved in a newer version, namely:

- pain ruler poorly scaled;
- few number of body regions to indicate pain symptoms;
- lack of right / left indication on the human body;
- icons of Anxiety page considered as infant-like.

Other features that could enhance the present communication system will be discussed in detail in the next chapter.

# Chapter 6

# Conclusions and Future Work

In this work, we developed a medical device for communication, based on an eye tracker and an interactive graphical user interface, targeting nonspeaking patients at ICU.

The objectives that we proposed to accomplish were successfully achieved.

This technology aims people at debility states and thus reliability, robustness, safety, and mounting issues were carefully taken into account. It does not require any kind of prior learning and thus can be applied in short-period stays or unpredictable hospitalizations at ICU.

It is also practical and easy to implement, not representing an extra charge on paramedics' working routines. The final device is cost-effective, which makes it affordable for the Health National System and tempting for private clinics.

The communication is established via figurative icons represented by symbolic images and texts so that the patients can inform the medical staff about their symptoms, location and intensity of pain, feelings and needs. This will ultimately access their health condition and improve their daily life at the hospital.

Usability tests conducted on healthy subjects proved that the system presents an intuitive and easy operating mode, enabling people of different ages to communicate clearly and understandably. If it had been available a more extensive working period, other parameters could have been tested, namely, the screen distance, the screen size, the default *dwell time*, the presence / absence of the gaze-locked point, the subjects' conditions and groups etc.

The survey conducted on users after GUI interaction showed that its design is appealing and allows an easy communication.

Since this system is in process of validation to be tested at the hospital, there is no information on practical cases to the date, nor concrete data on the patient's response. However, the review of the impact of providing AAC technologies to patients at ICU proved that these approaches are valuable and essential tools on improving life conditions at the hospital. Furthermore, the doctors' feedback was favourable since this device accomplishes the essential health and safety requirements, meets the needs of the patients and fills the gap of assistive technology for communication at ICU.

In the proposed medical device, some features could be enhanced leaving the door open for future interventions.

At first sight, the device could incorporate a speech synthesizer in order to reproduce loudly the patient's message. On a further stage, the device could be integrated on a networked infrastructure allowing, for example, the TV control using the respective menu. These enhancements would provide greater autonomy to the patient and leave the caregiver available to do more important tasks.

This device was created targeting patients from the pulmonology department. The GUI is directed to people who suffer interventions to the respiratory system and so, some of the options concern, specifically and exclusively, this sector. However, other health interventions involving intubation and mechanical ventilation, namely due to anaesthesia, would also benefit from this system. Therefore, new menus directed towards other hospital departments could be created. For that, it would be necessary to conduct a detailed study of each one of them, in order to obtain data related to the specific patients' treatments, problems and needs.

Alternatively, it could be developed an easy GUI allowing doctors and paramedical staff to modify the menu's structure according to the current needs and requirements of their department and patients. This upgrade would give the opportunity to adapt the system to each hospital department or even to each situation / patient. To date, if it is necessary to make any alterations or create new layouts, it is required someone with specific programming skills. Once it is not desirable to give further formation to the medical staff, an intuitive way to change and update the program would be an add-value to the present solution. On the other hand, the system was thought to be standard and directed to patients at ICU of one certain department. Standardization is important in order to discard the need for continuous adaptation.

In a broader application, the system could also be adapted to fit other cases of severe permanent motor impairment. The GUI was also adapted to patients with ALS. This test is under process with awaited results. The present system does not constitute an innovation in the field of AAC technologies targeting ALS patients, since many studies have been conducted and different devices have been developed for this population. However, this is, nonetheless, an available option that presents many advantages, namely its low-cost, ease to acquire and versatility of adaption to each person.

In a wider and higher perspective, this system could be used to have an advanced functionality of diagnosis. For the time being, the eye movements' data are exclusively used for functional purposes i.e., to select the buttons to where the patient is looking at. Additionally, the data of each patient could be saved and used for further purposes.

In an immediate analysis, one could evaluate how frequently the patient selects, for example, the icon “Anxiety”. This would describe a profile across different patients and even, for the same patient, across different days and health states. The same analysis could be done for the selection of “Pain”, to obtain an overview of the more frequently complains after a certain kind of intervention. Tracing such profiles could provide valuable information to enhance the postoperative care. In the same lines, the statistical study of the announcement of the everyday needs, such as room temperature or hungry/thirsty, could give important cues about the general hospital life conditions, but also help improving the way in which the institution’s physical and human resources are managed.

In a more ambitious outlook, data of the eye movements could be taken effortlessly to a higher level of in-depth analysis. The extensive data of patients could be applied on physiologic and psychophysics finalities. Pupil size is known to be affected by physical activation, strong emotional experiences and cognitive effort. Several studies have supported that it is possible to infer the physical and emotional state of one person from his eye features (see section 3.4).

Henceforth, the eye’s dynamics and pupil size extracted from the eye tracker may be fundamental in the assessment of the patient’s health and emotion conditions.

This analysis and consequent secondary function, either at a superficial or at a deeper level, would gather large and consistent data that could be useful for visual and oculomotor studies. This would be an innovative and ambitious project that would contribute to a better understanding of both individual user behaviour and statistical results from several users. However, this functionality and future application need further studies to confirm and validate a direct assessment of health/emotional status by analysing the gaze characteristics.

To conclude, by providing a communication way to nonspeaking patients at ICU, I expect to improve the interpretation of intentional messages and to reduce the sources of discomfort and stress that will ultimately improve patient’s life during the ICU stay and its aftermath. I hope that my contribution will improve the quality of life and promote the recognition of the patient as a person.

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# Annex 1

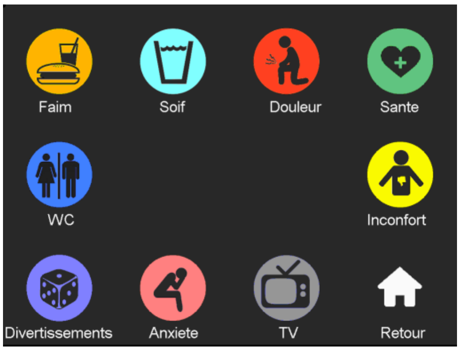
## Survey after navigation on graphical user interface

1. Is it easy to navigate through the menus? ________
2. Is the organization structure of menu confused? Too many sub-menus? ________
3. Is it difficult to maintain the gaze long enough to select? ________
4. Are the options being selected without wanting? System too "sensitive"? ________
5. Is the red dot following your eyes a distracting source? ________
6. Does the red dot stop matching with the screen region under gaze? ________
7. Is the feedback (jitter) useful? ________
8. Are the texts readable / big enough? ________
9. The combination of the text with the image allows clear understanding? ________
10. Is the colour associated with each icon helpful for the communication? ________
11. Is the overall design appellative? ________
12. Are the images infant-like? ________
13. Opinions / Comments:

# Annex 2

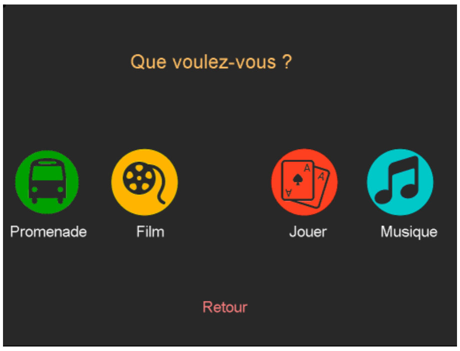
## Version of the graphical user interface addressed to ALS patients

In the Guided Communication page, the Breathing (*Respiration*) option was replaced by Entertainment (*Divertissements*) as shown in figure 6.1.




Once ALS patients do not have necessarily respiratory problems, the specialists suggested to delete that button and add a playful option.

**Figure 6.1** - GUI for eye communication adapted to ALS patients: Guided communication page.




In this new menu, the patient can chose between take a walk (*Promenade*), watch a movie (*Film*), play a game (*Jouer*) or listen to music (*Musique*).

**Figure 6.2** - GUI for eye communication adapted to ALS patients: Entertainment page.

Inside the pre-existent Bathroom's and Health's menus some adaptations were also taken into account.


Once ALS is a chronic disease, its medication is usually a single fixed dosage. Therefore, the icon to obtain information about medication was considered as irrelevant by the ALS specialists. However, these patients frequently depend on artificial ventilation. Thus, inside the menu Health, it was added the option "Need of Non-Invasive Ventilation" (*Besoin de VNI (Ventilation Non-Invasive))* as shown in figure 6.3.

**Figure 6.3** - GUI for eye communication adapted to ALS patients: Health page.


In the same way, the specialists that accompanied these patients suggested the alteration of the menu Bathroom. Therefore, the previous options were both replaced by "going to the bathroom" (*Aller au toilettes*) or "take a shower" (*Être lavé*).

**Figure 6.4** - GUI for eye communication adapted to ALS patients: WC page.