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Eye Tracking

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Päivi Majaranta,
Richard Bates, and
Michael Donegan

36.1 Introduction

People use their eyes mainly for observation, but people also use gaze to enhance communication; for example, staring at somebody soon causes a reaction: "What? Do you want something?" Similarly, an intense look at a water jug may be enough to motivate someone at a dinner party to pour more water for you. Thus the direction of a person's gaze not only allows observation by that person of the world around them, but also reveals and communicates their focus of visual attention to the wider world (Just and Carpenter, 1976). It is this ability to observe the visual attention of a person, by human or machine, that allows eye gaze tracking for communication.

In some cases, eye gaze may be the only communication option available for a person. For example, after a severe accident a person may not be able to speak, in which case, a doctor may ask the person to "look up" or "look down" as an indication of understanding and agreement. This method of communication can be expanded from a simple yes or no command to a full communication system by adding meaningful objects in the view of a user. An example of this approach is the gaze communication board (Figure 36.1). Here a board has pictures, commands, or letters attached to it, with the user selecting items on the board by looking at them. The person, or interpreter, on the other side of the transparent board interprets the message by following the eye movements of the user onto the differing targets. Such a system illustrates the simple communication power of eye gaze tracking.

Manual eye gaze tracking systems such as the E-Tran frame are not always convenient, private, practical, or possess all of the communication functions a user may wish to use. Hence, computer-based gaze communication systems have been developed where an eye tracking device and a computer replace the manual communication board. In these eye tracking systems letters (or any other symbols, images, or objects) are shown on a computer screen placed in front of the user. The user simply points and selects these items by looking at them, with an eye tracking device recording their eye movements and a computer program analyzing and interpreting their eye movements in place of the human operator of the E-Tran frame. Such a system forms a basic gaze communication system.

This chapter will briefly summarize the history of these eye tracking systems, and how the technology has developed and improved during the years, making eye control a real choice for people with disabilities. Thus, the focus of this chapter is on interactive use of eye tracking in real time as a form of assistive technology. Data collection and offline analysis of eye movements, and its diverse application to eye movement research in physiology, psychology, marketing, usability, and so on, are out of the scope of this chapter. For an overview of the various

FIGURE 36.1 A gaze communication board ("E-Tran frame"). The person on the other side of the board acts as a human eye tracker and interprets the direction of gaze through the transparent board.

applications of eye tracking, see, for example, Duchowski (2002) or Jacob and Karn (2003).

Various gaze communication systems have been developed since the late 1970s (Majaranta and Räihä, 2002), and pointing with the eyes has been found to be fast and easy for the user (Stampe and Reingold, 1995). However, interpreting a person's intentions from their eye movements is not a trivial task. The eye is primarily a perceptual organ, not normally used for control, so the question arises how casual viewing can be separated from intended gaze-driven commands. If all objects on the computer screen would react to the user's gaze, it would cause a so-called Midas touch (or perhaps Midas gaze) problem: "everywhere you look something gets activated" (Jacob, 1991). This problem can be avoided by *dwell time*, where objects are only activated with an intentionally prolonged gaze. Dwell time and other solutions are discussed in the following sections that introduce the basics of gaze input and eye control.

The obvious users of eye control technology are those for whom it is a necessity, for example, people who have lost most motor control of their body and only have control over eye movements. This may seem like a rare disability, but with modern medicine enabling longer-term survival from often severe injury or ongoing disability, such conditions are becoming increasingly common. Table 36.1 shows an estimate of the numbers of people with disabilities that might benefit from gaze-based communication in the European Union (EU) (Jordansen et al., 2005).

For example, a brain stem stroke may leave the person in a "locked-in" state: fully aware and awake but almost totally paralyzed. In this locked-in syndrome eye movements are often the only voluntary movement not affected by the paralysis. Another example is amyotrophic lateral sclerosis (ALS, or motor neuron disease, MND), which is a progressive, incurable disease in which the person gradually loses control over all voluntary muscle movement as the motor neuron system degenerates. In the late stages of ALS, eye movement may well be the only controllable movement left. In both examples, personality, memories, and intelligence may be left intact, and, although they may not be able to speak, this does not mean sufferers of these conditions cannot communicate. In fact, communication via eye movements is still possible. Note that in some cases all voluntary muscle movement is lost, including eye movements, and even more advanced techniques are needed, such as brain-computer interfaces (BCI; see Chapter 37, "Brain-Body Interfaces"; see also Wolpaw et al., 2002).

People who are unable to move but have good control over eye movements have traditionally been the best candidates for eye-tracking systems. As they do not move, this immobility can make tracking easier in contrast to people who can move (voluntarily or involuntarily, e.g., in the case of cerebral palsy) and are much harder to track due to their movements. However, eye control may still be a genuine *choice* for both types of users, as eye control can be faster and less tiring than, for example, a manual switch-based system or a head-pointing-based system. Eye movements are extremely fast, and gaze pointing locates and points at a target long before a manually controlled mouse cursor may reach it. Since people look at things before they act on them, this speed gives the impression that eye movements anticipate their action (Land and Furneaux, 1997), greatly enhancing interaction and communication.

Recent advances in technology have considerably improved the quality of eye-tracking systems, such that a far broader group of people may now benefit from eye control. This is illustrated

TABLE 36.1 Total People in the EU That Might Benefit from Gaze-Based Communication

Condition	Total Population
ALS/MND	27,000
Multiple sclerosis	135,000
Cerebral palsy	900,000
Quadriplegia (spinal cord injury)	36,000
Spinal muscular atrophy	54,000
Muscular dystrophy	126,000
Brainstem stroke	688,000
Traumatic brain injury	675,000
* Total	2,641,000

* *Of overall total of 450 million people in EU.*

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later in the chapter, where a series of case studies from user trials are reported showing the potential benefits of eye control technology.

36.2 History, Trends, and Current Technologies

36.2.1 The History of Eye Tracking

Early in the field of eye gaze tracking, eye movements were studied mainly to observe the nature of human eye movements, rather than to use these movements for communication. The first *eye-tracking devices* that produced objective and accurate data were highly invasive and uncomfortable. For example, the system developed by Delabarre in the late 1800s used an eyecup with a lever extending to draw the eye movements on a smoked drum. The eyecup was attached directly to the eye surface (which required anaesthetization with cocaine) and had a hole in it through which the test subject could see (Wade and Tatler, 2005). A breakthrough in eye movement research was the later development of the first "noninvasive" eye-tracking apparatus by Dodge and Cline in the early 1900s (Wade and Tatler, 2005). This was based on photography and light reflected from the cornea of the eye (the shiny reflective surface of the eye). Many basic properties and types of eye movements were categorized using Dodge and Cline's camera-based device or its later improved versions. The "Dodge Photochronograph" is considered the inspirer and first ancestor of the current video-based, corneal reflection eye-tracking systems discussed later.

The development of computing power enabled gathering of eye-tracking data in real time, as well as the development of assistive technology systems aimed directly at people with disabilities (e.g., Ten Kate et al., 1979; Levine, 1981; Friedman et al., 1982; Yamada and Fukuda, 1987; and Hutchinson et al., 1989, all of whom focused primarily on users with disabilities). 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 (Ten Kate et al., 1979), is shown in Figure 36.2. Here eye movements were detected by two phototransistors attached to the spectacles' frames (the frames are located on top of the device in Figure 36.2).

The Eye-Letter-Selector could not track eye gaze sufficiently accurately to allow direct selection of individual characters on the keyboard. Instead, it detected eye movements to the left or right and used these as a single or double eye-controlled switch system (Ten Kate et al., 1979). To enable typing the system adopted a column-row scanning procedure. Columns of letters were highlighted automatically one by one in sequence across the keyboard. When the scanning reached the column where the desired letter was, the user activated eye-switch by looking right. The system then scanned the rows in sequence down the selected (highlighted) column, and again, when the desired letter was reached, the user could select it by looking right. This enabled slow but effective eye typing.

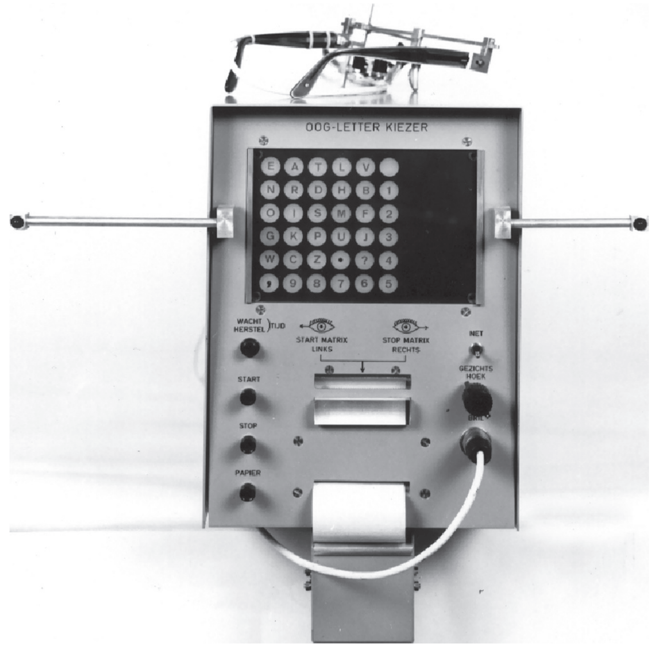

FIGURE 36.2 The Eye-Letter-Selector detected rough horizontal eye movements.[1]

36.2.2 Contemporary Technologies

Current eye-tracking technologies have evolved from the early systems such as the Eye-Letter-Selector into a range of technologies: electro-oculography (EOG) where the user wears small electrodes around the eye to detect the eye position (Figure 36.3), scleral contact lens/search coil where the user wears a contact lens with a magnetic coil on the eye that is tracked by an external magnetic system, video-oculography (VOG) or photo-oculography (POG) where still or moving images are taken of the eye to determine the position of the eye, and finally video-based combined pupil/corneal reflection techniques that extend VOG by artificially illuminating both the pupil and cornea of the eye for increased tracking accuracy (Figure 36.4; Duchowski, 2003).

Examining each of these approaches in turn, electro-oculography EOG-based systems may be seen as impractical for everyday use, because they require electrodes to be placed around the eye to measure the skin's electric potential differences. There are, however, EOG systems that are successfully used for augmentative and alternative communication (see, e.g., Gips et al., 1993; Hori et al., 2006). The EagleEyes system developed by Gips et al. (1993) has improved the quality of life of numerous users (Figure 36.3). There are some drawbacks, however, as some people may not wish to have electrodes placed on their face, and the electrodes can also fall off if the user perspires (Betke et al., 2002). EOG-based systems are not, however, sensitive to changes in lighting conditions (especially outdoor lighting), which is a considerable problem with video-based systems. As the EOG

[1] A detailed, illustrated description of the system and its later variations is available at http://www.ph.tn.tudelft.nl/~ed/ELS-Handi.html.

FIGURE 36.3 Eye paining with EagleEyes (http://www.eagleeyes.org). (Gips, J., DiMattia, P., Curran, F. X., and Olivieri, P., Using EagleEyes—An electrodes based device for controlling the computer with your eyes—to help people with special needs, in *Interdisciplinary Aspects on Computers Helping People with Special Needs, Proceedings of the 5th International Conference on Computers Helping People with Special Needs (ICCHP '96)* (J. Klaus, E. Auff, W. Kremser, and W. Zagler, eds.), 17–19 July 1996, Linz, Austria, pp. 630–635, R. Oldenburg, Vienna, 1996.)

potential is proportional to the angle of the eye in the head, an EOG-based mouse pointer is moved by changing the angle of the eyes in the head (EagleEyes, 2000). The user can move the mouse cursor by moving the eyes, the head, or both. More information about the EOG-based EagleEyes system is available in DiMattia et al. (2001) or at http://www.eagleeyes.org.

Systems that use contact lenses or in-eye magnetic coils are mainly used for psychological or physiological studies that require high accuracy (these systems can be very accurate to a fraction of a degree). Here gaze tracking is used to provide an objective and quantitative method of recording the viewer's point of regard. Such information can be used for medical and psychological research to gain insight into human behavior and perception (see, e.g., Rayner, 1995).

Video-oculography (VOG) and photo-oculography (POG) camera (video or still) based systems are considered to be the least obtrusive, and thus are best suited for interactive applications that react to the user's gaze at some level (Morimoto and Mimica, 2005). These systems tend to be inaccurate, and so are enhanced using pupil detection combined with corneal reflection to provide a point of regard (POR) measurement, which means that the system can calculate the direction of gaze (Duchowski, 2003). In practice, at least two reference points are required for the gaze point calculation. By measuring the corneal reflection(s) (from an infrared artificial light source aimed off-axis at the eye) relative to the center of the pupil, the system can compensate for inaccuracies and also for a limited degree of head movement. Gaze direction in these systems is calculated by measuring the changing relationship between the moving dark pupil of the eye and the essentially static reflection of the infrared light source back from the surface of the cornea. This approach relies on shining infrared light (to avoid the tracked subject squinting) at an angle onto the cornea of the eye, with the cornea producing a reflection of the illumination source (Figure 36.4).

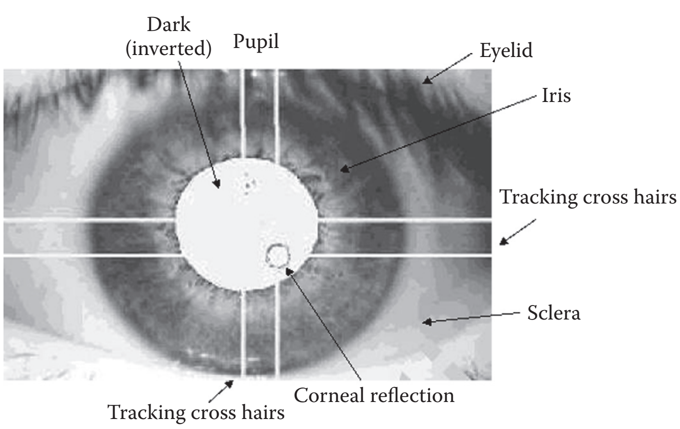

FIGURE 36.4 Video frame from a VOG system showing eye corneal reflection and pupil detection.

In operation the corneal reflection remains approximately constant in position during eye movement, hence the reflection will remain static during rotation of the eye and changes in gaze direction, thus giving a basic eye and head position reference. This reflection also provides a simple reference point to compare with the moving pupil, and so enables calculation of the gaze direction vector of the eye (for a more detailed explanation see Duchowski and Vertegaal, 2000).

Most of the currently available eye control systems are video-based (VOG) with corneal reflection, and hence this chapter concentrates mostly on these video-based systems.

36.2.3 Currently Available Eye Control Systems

Only a minority of the tens of currently available eye-tracking systems[2] are targeted at people with disabilities. Most of the systems use the same basic technical principles of operation, but

[2] For a list of eye trackers for eye movement research, analysis, and evaluation, see http://www.cogain.org/eyetrackers/eyetrackers-for-eye-movement-research.

TABLE 36.2 Commercially Available (Video-Based) Eye-Control Systems

Eye Response Technologies: ERICA (http://www.eyeresponse.com) Mouse emulation enables full control of Windows (typing, e-mail, web browsing, games etc.). Portable, flexible mounting options. Environmental control and remote IR control available as accessories. Touch screen and head control also possible. Comes with tablet/laptop PC, available for both Windows and Macintosh.
LC Technologies: Eyegaze (http://www.eyegaze.com) Dedicated, eye-controlled keyboard and phrases, which allows quick communication, synthesized speech. Access to Internet and e-mail. Play eye-controlled games (included), run computer software, operate a computer mouse. Includes also support for book reading, and control of lights and appliances (environmental control).
Tobii Technology: MyTobii (http://www.tobii.com) Dedicated eye typing, e-mail and gaze-controlled games included. Includes mouse emulation that can be used to control Windows. Dwell time, a switch, or an eye blink can be used to click. Tracks both eyes. Good tolerance to head movements. Long-lasting calibration with minor drifting. Accessories include a mounting arm. Available in several languages.
EyeTech Digital Systems: Quick Glance (http://www.eyetechds.com) Mouse emulation enables full control of Windows (typing, e-mail, web browsing, games, etc.). A switch or an eye blink can be used to click, in addition to dwell time selection. Several models available, with varying properties. Allows moderate head movements. Portable, comes with a tablet PC. Tracking module can also be purchased separately. Available in several languages.
Metrovision: VISIOBOARD (http://www.metrovision.fr) Mouse emulation enables full control of Windows (typing, e-mail, web browsing, games, etc.). Clicking can be done by dwell time (staring), eye blinks, or an external switch. Allows moderate head movements. Mounting arm for people in seated or lying position (cannot be attached to a wheelchair).
H.K. EyeCan: VisionKey (http://www.eyecan.ca) Head-mounted, lightweight, fully portable eye communication system. Comes with a stand-alone, separate control unit with a display (attached to eye glass frames) and a voice synthesizer, so no computer is needed when on the move. A standard USB keyboard interface is provided for computer control. Compatible with Windows or Macintosh. Provides scanning options for people with limited eye control. Independent of (nonviolent) head/body movements.

what makes certain systems suitable for people with disabilities are the applications (software) that are supported or come with the system and the (technical) support and accessories provided by the manufacturers and retailers. For a disabled person an eye control system is a way of communicating and interacting with the world and may be used extensively, daily, and in varying conditions by people with varying needs and (dis)abilities. Thus, reliability, robustness, safety, and mounting issues must be carefully taken into account, in addition to ease of use and general usability.

Currently available commercial eye control systems targeted at people with disabilities are listed in Table 36.2. The list only includes video-based systems that are operated by eye movements. Systems that use eyes as simple switches, such as systems based solely on eye blinks, are not listed, as these are not regarded as full eye-tracking systems and tend to offer more limited communication. The EOG-based EagleEyes is also excluded, as it is not sold, even though it is available (for free) to qualified users from a foundation in the United States (for more information, see http://www.eagleeyes.org). All the systems listed in Table 36.2 are in daily use by people with disabilities.

36.3 Basics of Gaze Input

36.3.1 The Nature of Eye Movements

Briefly addressing the nature of eye movements, we know that we look at things by holding our gaze relatively still[3] on an object for a short while, long enough for the human brain to perceive the nature of the object. Such a fixation typically lasts approximately 200 to 600 ms. Between fixations, gaze jumps rapidly from one object to another, with these saccades typically lasting approximately 30 to 120 ms. Saccades are ballistic movements; once a saccadic jump has been started, it cannot be interrupted nor can its direction be changed. In addition to saccadic eye movements, eyes can also smoothly follow a moving target, known as (smooth) pursuit. Normal eye movement is thus made from fixations on objects of interest joined by rapid saccades between those objects, with occasional smooth pursuit of moving objects.

[3] The eyes make very small, rapid movements even during fixations to keep the nerve cells in the retina active and to correct small drifting in focus. These “tremors” and “microsaccades” are so small that they are of little importance for practical applications of eye tracking.

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Examining the retina within the eye, the size of the high-acuity field of vision, the *fovea*, gives accurate vision that subtends an angle of about 1 degree from the eye. To illustrate this approximately, this angle from the eye corresponds to an area about the size of a thumbnail when looking at it with the arm straightened. Everything inside this foveal area is seen in detail, with everything outside this narrow field seen indistinctly. Thus, people only see a small portion of any full scene in front of them accurately at a time—it is this narrow vision that generates the need to move the eyes rapidly around to form a full view of the world. The farther away from the fovea an object is, the less detailed it appears to the human eye. The remaining peripheral vision provides cues about where to look next, and also gives information on movement or changes in the scene in front of the viewer (for more information about eye movements and visual perception, see, e.g., Haber and Hershenson, 1973).

Since the foveal area of acute vision is fairly small, and because people actually need to direct their gaze nearly directly toward an object of interest to get an acute view of the object (within 1 degree or so), tracking the gaze direction is possible—if the eye is pointing at an object, the user is probably looking and perceiving that object.

36.3.2 Calibration

Before a VOG eye-tracking system can calculate the direction of gaze, it must be calibrated for each user. This is usually done by showing a few (e.g., nine equally spaced) points on the screen and asking the user to gaze at the points, one at a time (Figure 36.5). The images of the eye are analyzed by the computer and each image is associated with a corresponding screen coordinate. 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.

Most current eye-tracking devices achieve an accuracy of 0.5° visual angle from the user (this is the equivalent of a region of approximately 15 pixels on a 17" display with resolution of 1024 × 768 pixels viewed from a distance of 70 cm). The practical accuracy of the system may be less because of "drifting," where over time the measured point of gaze drifts away from the actual point of gaze. This drift is caused by the changes in the characteristics of the eyes, and is mainly due to changes in pupil size, and excessive movement of the head resulting in the eye moving away from the clear view of the camera and the original calibration position. The effects of drifting can be taken into account and be dynamically corrected to some extent (Stampe and Reingold, 1995). Inaccuracy in pointing is corrected by realigning the possibly inaccurate measured gaze position onto the center of any object selected. It is (often correctly) assumed that the user is looking at the center of the object he wishes to select. Thus, if the measured point of gaze does not match the coordinates on the center of the object, it is possible to correct the drift by realigning the measured gaze position onto the center of the object—where the user is most probably looking at—thus correcting the drift.

Some eye-tracking systems have additional techniques for preventing drifting. Using data from both eyes may help, as the system may continue with data from one eye if the other is lost. For example, the Tobii tracker uses averaged data from both eyes to minimize the drifting effects (Tobii, 2006). This binocular averaging enables a long-lasting calibration with very little drifting and saves the user from continuous recalibrations.

A VOG eye tracker must have an unobstructed view of the eye and pupil to be able to track the eye. Eyelids or lashes may partially cover the pupil and ambient light or reflections from the environment may cause problems. Spectacle lenses or frames may cause extra reflections, and when contact lenses are used, the reflection is obtained from the surface of the contact lens instead of the cornea. This can cause problems if the lenses are displaced over time, causing degradation in tracking accuracy. Problems may also be prevented or minimized by careful setup, for example, by minimizing changes in the lighting conditions and positioning the camera so that it has a clear view of the user's eye (Goldberg and Wichansky, 2003). Finally, most

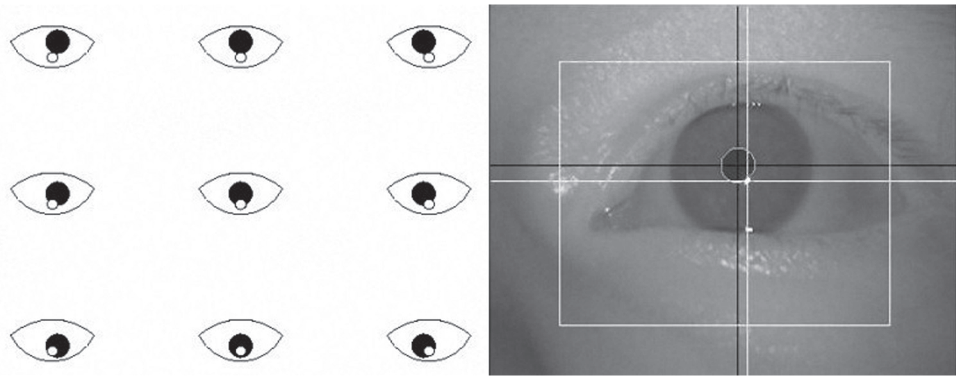

FIGURE 36.5 An illustration of pupil movements (black circles) and near stationary corneal reflections (smaller white circles) as seen by eye tracker's camera at each of the nine calibration points (left) and an image taken by an eye tracker's video camera (right). Note how the relationship between pupil and corneal reflection changes as the eye gaze direction changes.

eye-tracking systems have problems with severe involuntary head or eye movements. Certain medical conditions[4] may also prevent a successful calibration (Donegan et al., 2005). In some cases, calibration may be totally impossible or very inaccurate. If the calibration fails, some systems can be used with a default calibration, and special filtering of eye movements can be applied if the user has eye movement disorders (Charlier et al., 1997).

36.3.3 Gaze Pointing

Eye movements are so rapid that it is not always easy to realize how much and how often the eye moves. Gaze is easily attracted (or distracted) by movement in the peripheral vision, resulting in unwanted flicks away from objects of interest. Eye movements are also largely unconscious and automatic; people do not normally need to think where to look. When needed, however, one can control gaze at will, which makes eye control possible.

Gaze pointing, or placing the computer mouse cursor where the user is looking on the computer screen, is an intuitive method that requires little training (Stampe and Reingold, 1995), as it mimics the operation of a normal desktop mouse. However, it should be noted that for a profoundly disabled person who does not have prior experience on any method of computer control, it may take time to master a gaze-pointing eye control system (Donegan et al., 2006b; Gips et al., 1996).

36.3.4 Midas Touch and Selection Techniques

As the same communication modality, gaze, is used for both perception (viewing the information and objects on a computer screen) and control (manipulating those objects by gaze), the system should be able to distinguish casual viewing from the desire to produce intentional commands. This way the system can avoid the Midas touch problem, where all objects viewed are unintentionally selected (as introduced earlier; Jacob, 1991). The obvious solution is to combine gaze pointing with some other modality for selection. If the person is able to produce a separate "click," then this click can be used to select the focused item. This can be a separate switch, a blink, a wink, a wrinkle on the forehead, or even smiling or any other muscle activity available to that person (Ware and Mikaelian, 1987; Surakka et al., 2003, 2004; Fono and Vertegaal, 2005; Monden et al., 2005). In addition, blinks and winks can be detected from the same video signal used to analyze eye movements, removing the need for additional switch equipment. As muscle activity may be extremely faint or weak, it is typically measured by electromyography, EMG, of any available working muscles. Some systems are based solely on blinks or winks (using the eyes as kind of switches), without tracking gaze direction. For more information about such systems, see, for example, Barreto et al. (2000) or Grauman et al. (2003).

If a user is only capable of moving their eyes, separate switches are not an option, and the system must be able to separate casual viewing from intentional eye control. The most common solution is to use dwell time, a prolonged gaze, with a duration longer than a typical fixation (typically, 500 to 1000 ms; see, e.g., Hansen et al., 1995, 2003a; Istance et al., 1996; Velichkovsky et al., 1997; Majaranta and Räihä, 2002). Most current eye control systems provide adjustable dwell time as one of the selection methods. Requiring the user to fixate for a long time does reduce false selections, but it is uncomfortable for the user, as fixations longer than 800 ms are often broken by blinks or saccades (Stampe and Reingold, 1995). A long dwell time may also be tiring to the eyes and hinder concentration on the task (Majaranta et al., 2006).

Another solution for the Midas touch problem is to use a special selection area (Yamada and Fukuda, 1987) or an onscreen button (Ohno, 1998). For example, in the "quick glance" method developed by Ohno (1998), each object that could be selected was divided into two areas: command name and selection area. Selection was made by first fixating briefly on the command (to determine the name or type of the command) and then confirming that a selection was required by fixating briefly on the selection area. Alternatively, if the user is experienced and knows the locations of commands, she needs to only glance directly at the selection area associated with that command.

Sometimes gaze is unfocused or undirected when the attention of a user is not directed at interaction with the screen. For example, a user may be concentrating or thinking about something, and while thinking his eyes may wander about the screen and accidentally or unconsciously point at an object. Since the eyes are always "on" (they are always pointing unless closed), there is always a risk (and an annoyance and fear) of accidentally staring at an object that is then unintentionally selected. This results in the user feeling that she may not fully relax. Thus, in addition to a long enough dwell time, it is beneficial to the user if eye control can be paused with, for example, an onscreen Pause command to allow free viewing of the screen without the fear of Midas touch (Donegan et al., 2006a).

36.3.5 Accuracy Limitations

The accuracy of the measured point of gaze is a problem if a user wishes to use gaze as her main method to control a standard graphical computer interface. Many of the target objects on typical graphical user interfaces are smaller than the area of high acuity vision (subtending less than 1 degree across at a normal viewing distance from the screen). Even if eye trackers were perfectly accurate, the size of the fovea restricts the practical accuracy of systems to about 0.5° to 1°. Everything inside the foveal region is seen in detail, and the eye may be up to 1 degree away from the object and still perceive it. Also, attention can be retargeted within the foveal region at will without actually moving the eyes. Thus, gaze is not as accurate an input device in comparison to other devices such as a desktop hand mouse, but it can be much faster at pointing due to the speed of the eye if the target objects on screen are large enough (Ware and Mikaelian, 1987; Sibert and Jacob, 2000).

[4] For more information about medical conditions that may allow or prevent using an eye-gaze system, see, for example, http://www.eyegaze.com/2Products/Disability/Medicaldata.html.

Thus increasing the size of the targets on the screen makes them easier to "hit" and improves the performance of eye gaze input, and this results in objects designed for eye gaze control often being quite large on screen. However, having only a few, large buttons on screen at a time prevents the use of full-size keyboards such as a full QWERTY keyboard. Instead, keys and controls can be organized hierarchically in menus and submenus, and special techniques such as automatic word prediction can be used to speed up the text entry process, with ambiguous or constantly changing and adapting keyboard layouts (see, e.g., Frey et al., 1990; Hansen et al., 2003b). As an example, GazeTalk (Figure 36.9) has large buttons that support users who have difficulty getting or maintaining a good calibration, or it may be used to enable the use of an eye tracker with a low spatial resolution. It also aids typing speed by changing the keyboard layout using a language model to predict the next most probable letters.

It is important to acknowledge that eye control can be an option to consider even with a very poor calibration. Making onscreen objects much larger can make a difference between a user being able to use an eye-tracking device or not being able to use it at all (Donegan et al., 2005).

36.4 Assistive Applications of Eye Tracking

When an eye tracker is used as an assistive device, it provides a way of communication for a person who cannot talk, and a way of interacting with the world for a person whose mobility is restricted. This section discusses ways of implementing the most common functions of eye control, and provides a few examples of gaze-controlled applications, discussing special design issues that arise from using gaze input.

36.4.1 Mouse Emulation

As introduced earlier, a common way of implementing eye control is to use eye movements to control the mouse cursor. Binding eye movements directly to mouse movements to create an eye mouse may seem an easy solution; however, there are several issues that have to be taken into account.

Eyes move constantly, and eyes make small corrective movements even when fixating. If the cursor of such an eye mouse followed eye movements faithfully without any *smoothing*, the cursor movement would appear very jerky and it would be difficult to concentrate on pointing, as the cursor itself would attract attention (Jacob, 1993). Applying proper smoothing (by averaging data from several gaze points) "dampens" down the jitter, making visual feedback more comfortable and less disturbing (Lankford, 2000). Smoothing the cursor may also assist in maintaining the pointer on target long enough for it to be selected. On the other hand, smoothing slows down the cursor movement. Some applications, such as action games or the Dasher text entry system (Ward and MacKay, 2002), benefit from faster response. Thus, it should be possible to adjust the amount of smoothing (Donegan et al., 2005).

If calibration is poor, the cursor may not be located exactly where the user looks, but a few pixels offset. This may cause users to try and look at the cursor that is displaced away from the actual point of gaze: as the user moves his gaze to look at the cursor, being a few pixels offset, the cursor again moves away from the gaze point. This causes users to chase the cursor that is always a few pixels away from the point the user looks at (Jacob, 1995). Experienced users may learn either to ignore the cursor or to take advantage of the visual feedback provided by the cursor to compensate for any slight calibration errors by adjusting their own gaze point accordingly to bring the cursor onto an object (Donegan et al., 2006b).

The accuracy of eye pointing is restricted to about 1 degree or less, depending on the success of the calibration. If screen resolution is set low and large icons are used, people with good, stable eye control may be able to use standard graphical user interfaces (such as Windows) directly by eye gaze (see, e.g., Donegan et al., 2006b). Special techniques, such as zooming or temporarily enlarging an object on the screen (Bates and Istance, 2002) or a fisheye lens (Ashmore et al., 2005) help in selecting tiny objects such as menu items or shortcut buttons in a typical Windows environment. Figure 36.6 shows an example of using the Zoom tool included in the Quick Glance's Eye Tools menu to magnify a portion of an image.

A mouse click can be executed by dwell time, blink, switch, or any other selection method described previously. In addition to single (left) mouse click, right click, double click, and dragging are also needed if full mouse emulation is desired. These functions are typically provided in a separate (Mouse Click) menu, such as the Quick Glance's Eye Tools menu shown in Figure 36.6. An alternative solution is, for example, to use a short dwell time for a single click and longer dwell time for a double click (Lankford, 2000). Feedback on the different stages of the dwell time progress can be shown in the cursor itself by changing its appearance. It may, however, be difficult for some people to understand the different stages.

The main benefit of using mouse emulation is that it enables access to any windows, icons, menus, pointer based (WIMP) graphical user interface. In addition, and as important, it enables the use of any existing access software, such as environmental control applications or dwell click tools. There are also applications that allow the user (or a helper) to design her own special access keyboards with varying target sizes and layouts (for more information of the possibilities and examples of applications, see Donegan et al., 2005).

36.4.1.1 Eye Mouse versus Head Mouse

Perhaps the closest alternative to eye pointing for the users detailed in Table 36.1 is using the head to point if they retain some head control. Obviously, the main difference between eye pointing and head pointing is that, when pointing with a head mouse, the eyes are free for viewing. If the user has good head control, a head mouse can also be quite accurate. Considering the

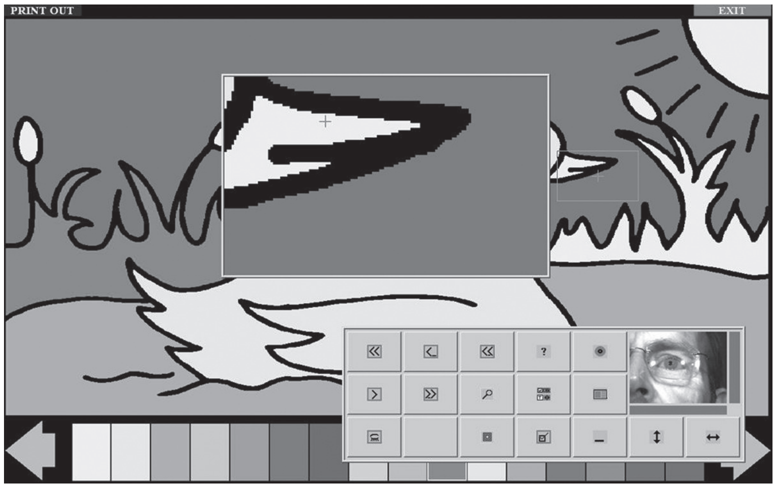

FIGURE 36.6 Quick Glance's Eye Tools menu provides a zoom tool for target magnification in addition to mouse actions (double click, right click, dragging, etc.), quick calibration correction, and other options. (From EyeTech, 2005.)

availability and price of head mice[5] (even a mid-price-range eye control system would be far more expensive than a head mouse), a head mouse could be a better choice than an eye mouse for those who can use it, although anecdotal evidence suggests concerns over prolonged exposure of the neck to repetitive pointing tasks.

Bates and Istance (2002, 2003) compared eye mouse and head mouse in a real-world test that consisted of various simple tasks using a word processor and an Internet browser. Overall, head mouse performance and user satisfaction for the head mouse was higher than for eye mouse. However, the results suggest that an eye mouse could exceed the performance of a head mouse and approach that of a hand mouse if target sizes were large. Performance increased with increased practice; with experienced eye mouse users reaching head mouse performance, though it seems to require more training to master an eye mouse than a head (or hand) mouse.

Hansen et al. (2004) obtained similar results when comparing eye typing with input by head or hand. They tested eye performance using the onscreen keyboards Dasher (Ward and MacKay, 2002) and GazeTalk (Hansen et al., 2001) in Danish and in Japanese. Gaze interaction was found to be just as fast as head interaction, but more erroneous than using head or hand mouse.

The user should have a choice of choosing eye or head mouse, depending on the task and the physical condition of the user, as suggested by a user who tried eye control and was impressed by it (Donegan et al., 2005). For her, eye control felt more natural and requires less effort than either the mouthstick (her main interaction method) or head mouse.

5 A comparison of head pointers is available at the ACE Centre's web site at ace-centre.hostinguk.com.

36.4.2 Typing by the Eye

Communication is a fundamental human need, and difficulties in communication may lead to loneliness and social isolation. Developers of eye control systems are well aware of this and so eye typing is typically the first application implemented and tried out by users with an eye control system, with such eye-typing systems being available since the late 1970s (Majaranta and Räihä, 2002).

In a typical eye-typing system, there is an onscreen keyboard (there is no need to adhere to a QWERTY layout), an eye-tracking device that tracks the user's gaze, and a computer that analyzes the user's gaze behavior. To type by gaze, the user focuses on the desired letter by looking at one of the keys on the onscreen keyboard. Selection is typically made by dwell time, or alternatively, using any of the selection methods discussed earlier. Typed text appears in the input field, often located above the keyboard (Figure 36.7).

Eye typing can be slow, typically below 10 words per minute (wpm), due to dwell time durations setting a limit on the maximum typing speed. So, for example, with a 500 ms dwell time and a 40 ms saccade from one key to another, the maximum speed would be 22 wpm. In practice, entry rates are far below that (Majaranta and Räihä, 2007). People need time for cognitive processing, to think what to type next, to search for the next key on the keyboard, to correct errors, and so on.

Ward and MacKay (2002) developed a writing method, Dasher, that enables efficient text entry by gaze using continuous (gaze) pointing gestures. Dasher requires no selection or dwell time at all. Everything is done by using the direction of gaze. The user navigates by pointing at the letter(s) on the right side of the screen. As soon as the cursor points at a letter, the letter starts to fly or expand and move left toward the center of the window. The letter is selected (written) when it crosses the vertical line in the center. For example, in Figure 36.8, the letter *t* has just been selected. This movement and expansion results in the letter becoming

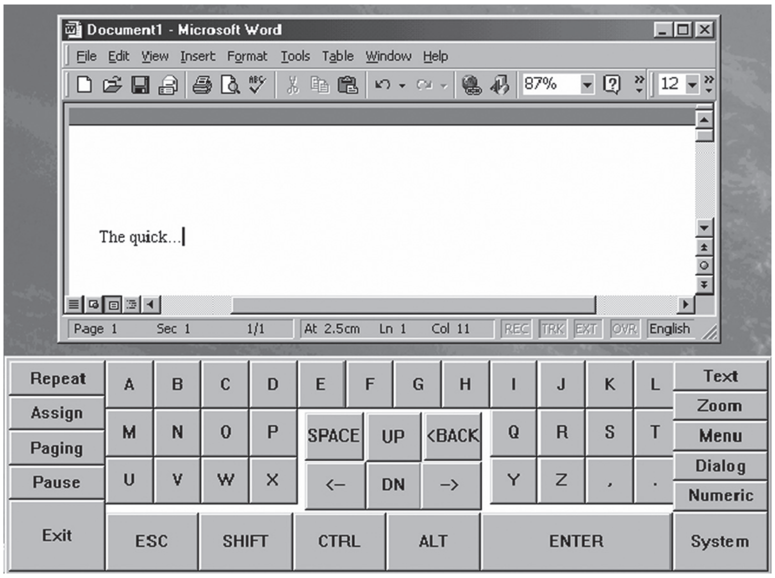

FIGURE 36.7 EC Key, a typical gaze-driven keyboard. (From Istance, H. O., Spinner, C., and Howarth, P. A., Providing motor impaired users with access to standard Graphical User Interface (GUI) software via eye-based interaction, in the *Proceedings of the 1st European Conference on Disability, Virtual Reality and Associated Technologies (ECDVRAT 1996),* 8–10 July 1996, Maidenhead, U.K., pp. 109–116, http://www.icdvrat.reading.ac.uk/1996/papers/1996_13.pdf, 1996.)

large and easy to point at just before it crosses the vertical line, enabling accurate selection of the letter. Canceling is done simply by looking left of the center line, which causes the flying to reverse and the typing to be undone. Dasher embeds the prediction of next letters into the writing process itself. Letters that are more probable get more space and appear larger on the screen, and therefore are easier to locate with the cursor. In Figure 36.8, the user is in the middle of entering gaze writing, with letters *writ* already entered and pointing at *ing*. Writing is efficient and easy because several letters can be selected with one gesture. Learning to write with Dasher takes more time than learning to eye type with an onscreen keyboard, but it is much faster once mastered. Dasher is the fastest gaze-writing system at the moment (25 to 34 wpm). Further information about different approaches to text entry by gaze is available in Majaranta and Räihä (2007).

Communication is more than just producing text, and eye typing feels especially slow in face-to-face communication situations, as its entry rate is far below that of human speech (150 to 250 wpm). Ready-made greetings and phrases can speed up everyday communication, and a speech synthesizer can give the user a voice and the ability to speak aloud. However, the synthesized voice may not feel right if it is not age and gender specific (Friedman et al., 1982). Since the user must look at a computer monitor to communicate, this greatly alters the communication between the user and other people. The normal eye-to-eye contact of typical communication is broken and facial expressions cannot be so easily viewed by the user whose attention is focused on the screen. Due to this loss of facial communication, a see-through communication board may even feel more natural for everyday communication because people maintain a face-to-face connection (see Figure 36.1). The communication board can also be used everywhere and it is always reliable and does not crash. Besides, an experienced human interpreter[6] is a far more effective word predictor than any of the computer-based systems that do not understand conversational context and situation and are not able to understand humor, and so on. There is still a need for more effective textual gaze communication.

36.4.3 Drawing by the Eye

It is simple to bind the mouse movement to the eye movement and then just select the paint tool, as is done in Figure 36.3, where a thick line with varying colors follows the user's eye movements. However, drawing recognizable objects (houses, trees, people) is not easy with free-eye drawing (Tchalenko, 2001). The characteristics of eye movements prevent using the eyes as a pencil to sketch a finely defined shape. For example, since eye movements are ballistic, it is easy to draw a fairly straight direct line from point A to B just by glancing at the starting and ending point. However, trying to draw slowly or trying to draw a curved line is hard, since the eye does not easily fixate on empty white space and does not move smoothly but in saccadic jumps. Thus, an eye-drawn circle would not be a smoothly curved circle, but would be more like a multi-angled polygon with many small jumps. The human eye needs a moving target to follow to initiate smooth (pursuit) movement.

The Midas touch problem is also strongly present: is the user moving his eyes to draw, or is he looking at the drawing?

[6] After years of practice, one may learn the locations of letters and no longer need the board; each letter has its position in thin air (http://www.cogain.org/media/visiting_kati).

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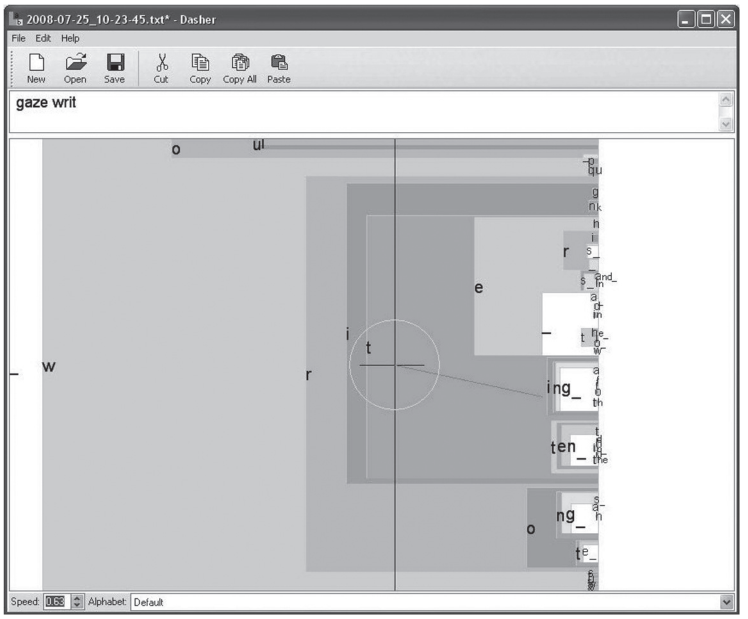

FIGURE 36.8 Dasher predicts the next probable, consecutive letters.

A method for distinguishing between drawing and looking is needed. Hornof et al. (2004) developed EyeDraw, which implements a set of eye-controlled tools for drawing and painting. Using the tools, the user manages the drawing process assisted by the tools, rather than attempting free-eye drawing. For example, to draw a line, the user first looks at the Draw Line button in the tools menu. The button is highlighted after dwelling on it to show that the Draw Line tool is active. To draw the line, the user then moves the cursor to the location where the drawing should start and dwells on it. The cursor color changes to show that the starting point has been defined. From now on, a straight line, with its other end fixed on the starting point, starts to follow the user's gaze. Again, the user has to dwell on the selected location to define an ending point for the line. By changing the color of the cursor, the program provides feedback on the current state, which can be either looking or drawing.

Defining the starting point by staring at a blank drawing surface is somewhat difficult, as the eye does not easily fixate without a target object of interest. Also, if calibration is inaccurate and the cursor offset from the actual gaze position, then looking at the eye-driven cursor for a visual anchor point does not work, as fixating at the cursor would only move it away from focus due to calibration inaccuracy, causing the user to chase the cursor across the screen. Therefore, EyeDraw provides a grid of dots that act as visual anchors and help in placing the starting and ending points, literally, on the dot. EyeDraw has been successfully used by people with disabilities to produce drawings, although younger children may get frustrated as they may not have the patience to learn the tools and different states (Hornof and Cavender, 2005). For them, free-eye drawing provides an easy start with immediate positive feedback.

In addition to eye typing and eye drawing, there are several (dedicated) eye-controlled applications, such as eye music (Hornof and Sato, 2004), Internet browsing, e-mail, games, and so on. Such applications are included in many of the commercial eye-control systems targeted at people with disabilities (see Table 36.2).

36.5 Visual and Auditory Feedback

Appropriate feedback is important when the same modality is used for both control and perception. When using gaze to control an application and select objects on screen, gaze is engaged in the input process: the user needs to look at an object to select it. This means that the user cannot simultaneously control an object and view the effects of the action, unless the effect appears on the object itself. For example, if the user is entering text by gaze, she cannot see the text appear in the text input field at the same time she selects a letter by "eye pressing" a key on an onscreen keyboard. To review the text written so far, the user needs to move her gaze from the onscreen keyboard to the typed text field. This looking back and forth can become excessive, especially as novices often shift their gaze between the keyboard and the text input field to review the text written so far (Bates, 2002). This shifting can be reduced by adding auditory feedback, for example, an audible click, or by speaking out each letter as they are written. Appropriate feedback also increases performance and improves accuracy. Even a slight improvement in performance makes a difference in a repetitive task such as text entry, in which the effect accumulates character by character (Majaranta et al., 2006).

Experienced users learn to cope with having to use the same modality for input (control) and output (feedback); they complete the task (e.g., scrolling) before gazing at the results (Bates, 2002). Providing appropriate feedback on the dwell time progress (see Figure 36.9) and the selection process may significantly improve performance and make eye control more pleasant for the user (Majaranta et al., 2006). There is a fundamental difference in using dwell time as an activation command compared to, for example, a button click. When manually clicking a button, the user makes the selection and defines the exact moment when the selection is made. Using dwell time, the user only initiates the action; the system makes the actual selection after a predefined interval. When physically clicking a button, the user also feels and hears the button click. Such extra confirming (auditory or tactile) feedback is missing when an eye press is used to click, and so must be provided.

Many eye tracking manufacturers provide applications that are specifically developed for eye control. The main advantage of such dedicated applications is that the many special requirements of gaze interaction already introduced in this chapter can better be taken into account. So, for example, the layout and the structure of the application can be designed so that items are large enough to be easily accessible by gaze. The feedback provided by a dedicated application can be implemented so that it supports the process of gaze pointing and dwell time selection. As introduced previously, the constant movement of the eye cursor may disturb some users. This may be avoided by hiding the cursor completely, but then another kind of (visual) feedback is needed. This feedback can be shown directly on the item being gazed at by highlighting the button, for example, by bordering the button or changing its background color.

Showing the feedback on the center of the focused item, rather than the actual (potentially slightly inaccurate) position of the gaze, seems to be especially useful for some users (Donegan et al., 2006b). If the feedback is animated inward or toward the center of the button, it may help the user to maintain his gaze focused in the center for the full duration of the dwell time (Majaranta et al., 2006). This, in return, may be helpful if calibration is poor, as when the feedback is shown at the center of a gaze-responsive button, the calibration appears to be perfect to the user, encouraging the user to feel confident when using gaze.

36.6 Results from User Trials

This section summarizes some of the key findings from the user trials conducted within COGAIN, a European Network of Excellence on Communication by Gaze Interaction (http://www.cogain.org). The network combines the efforts of researchers, manufacturers, and user organizations for the benefit of people with disabilities. COGAIN works to spread information about eye-control systems, to identify users' real needs, to improve the quality of eye-control systems, and to develop new hardware and software solutions (Bates et al., 2006). The authors of this chapter are members of the network.

An extensive study on user requirements by Donegan et al. (2005) shows that, to date, eye control can effectively meet only a limited range of user requirements, and that it can only be used effectively by a limited number of people with disabilities. Furthermore, the range of applications that are suitable for easy and effortless control by the eye is limited. COGAIN works to make eye control accessible to as many people as possible.

The results reported here summarize some of the key findings from COGAIN user trials and usability studies (mainly Donegan et al., 2006b, but also Donegan et al. 2005, 2006a). The trials have involved many users from across Europe, with varying disabilities, such as ALS/MND, locked-in syndrome, multiple sclerosis, (athetoid or dyskinetic) cerebral palsy, severe brain damage, and spinal muscular atrophy. Several eye-control systems from different manufacturers have been used in the trials, including both brief one-time trials as well as a series of long-term trials.

36.6.1 Potential Users with a Wide Range of Abilities and Disabilities

When listing potential user groups of eye-control technology, people with ALS are usually among the highest priority as people who most need and benefit from eye control. In the late stages of ALS, control over all other body movements may be lost, but the person can still move his eyes. COGAIN user

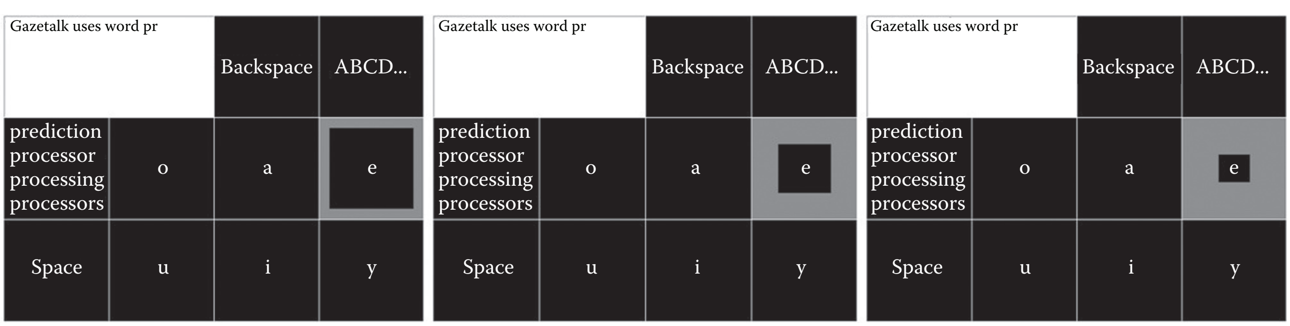

FIGURE 36.9 GazeTalk[7] provides visual feedback on the dwell time progress on letter *e*.

[7] GazeTalk (Hansen et al., 2001) is freely available at http://www.cogain.org/downloads.

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trials, conducted by Politecnico di Torino and the Torino ALS Centre, have confirmed that people with ALS may greatly benefit from eye control. The participants especially appreciated the ability to use applications independently. Such independency is not possible with their other methods of communication, such as the E-Tran frame (shown in Figure 36.1), which relies on a communication partner. Eye control also facilitated more complex communication. The participants felt that they were able to express more than only their primary needs (for detailed results, see Donegan et al., 2006b). It is important to spread information about eye control and its potentials. This lack of information was highlighted as before participating in COGAIN user trials the majority of the participants were not aware that it is possible to write a letter, play chess, send an e-mail, or communicate needs, emotions, and problems just by eye gaze alone.

Eye control suits people with ALS well, because they have good visual, cognitive, and literacy skills. They also do not have involuntary movement, so their eyes are fairly easy to track. However, there are people with a wide range of complex disabilities who might also benefit greatly from eye control, but who find it difficult because of involuntary head movement, visual difficulties, or learning difficulties. The ACE Centre in the United Kingdom and DART, the regional center for AAC and computer access in western Sweden, deliberately chose to work with users with complex disabilities who still might benefit from eye control. They found strong indications that eye-control technology can have a positive impact on communication ability and, subsequently, quality of life. Results also showed that there are many issues that may lead to failure or success in trialing gaze control with users with complex disabilities. Examples of such key issues are discussed in the following, and suggestions for a successful assessment are made.

36.6.2 Initial Setup and Hardware Challenges

36.6.2.1 Positioning

The quality and accuracy of gaze control is directly related to the success of the calibration. Having a flexible mounting system was found to be necessary in all cases of the user trials, and this enabled the eye-control system to be safely positioned for optimal comfort, function, and visibility. Most eye trackers have an optimal distance and optimal angle in relation to the user's eyes, and it was found that poor positioning may lead to poor or totally failed calibration.

For example, one participant (Bjorn in Figure 36.10) used the system in a side-lying position where he maintained a very stable head position. He had excellent eye control and was able to have full control over all Windows applications by controlling the cursor with his eyes, combined with an onscreen keyboard. However, those participants who had either involuntary head movement or visual difficulties (e.g., nystagmus) were found to be less accurate, though in most cases this could be compensated

FIGURE 36.10 A side-lying position enables maintaining a very stable head position.

for by personalized grid-based interface software such as The Grid, Rolltalk, SAW, and so on.[8]

36.6.2.2 Environmental and Situational Factors

It was found that a range of environmental (e.g., lighting conditions) and situational factors (e.g., anxiety) may contribute to the success—or failure—of the calibration. As eye control is a new technology, there is great interest in attending eye-control user trials. However, having too many people around may disturb the user and make concentration difficult. During the trials, it also became apparent that eye control is often tried when all other options have failed, and so expectations are high. If the trial is a failure, it should be made clear that it was not the fault of the user. It is important that the user (and anybody involved) retains a positive attitude for any future trials.

36.6.2.3 Finding the Best System for Each User

Some of the participants tried out several systems before an appropriate system was found. Finding a system that accommodates the physical and perceptual needs of the user may be essential for the success of the trial. For example, many of the users had spasm or involuntary head (or eye) movement that required a tracker that was able to accommodate to them.

For example, Michael has difficulty with head control. In addition, he has involuntary side-to-side eye movement (nystagmus), which becomes more severe when he is tired. The nystagmus made calibration very difficult or impossible, depending on the eye-tracking device. When the nystagmus was at its most severe level, none of the currently available trackers were able to cope with it. When Michael did achieve a successful calibration, the

[8] The Grid is available from Smartbox (http://www.smartboxat.com); Rolltalk is available from Igel (http://www.rolltalk.com); and SAW is available from The ACE Centre (http://www.ace-centre.org.uk).

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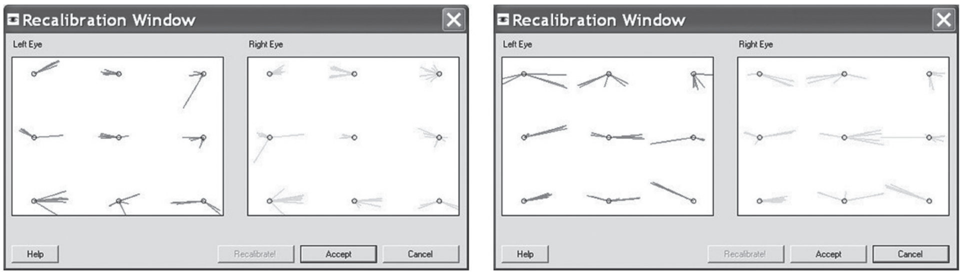

FIGURE 36.11 Success in calibration varied depending on the severity of nystagmus. Calibration on the left enables using a grid with smaller cells compared to the calibration on the right that shows large involuntary movement around the nine target calibration points.

increased speed, comfort, and satisfaction (in comparison with switches) made him extremely enthusiastic about eye control. When the nystagmus was not severe (see Figure 36.11), he was able to use a 2 × 4 grid. However, he preferred to write using a less efficient 2 × 2 grid because it required less effort from him.

36.6.2.4 Customized Calibration

It was found useful to be able to manually adjust the calibration process. Some of the participants (especially those with learning disabilities or brain damage) had trouble following the automatic calibration procedure. Some of the users also had trouble in visually accessing the full screen, and one participant was only able to move his eyes horizontally. It was found to be useful if the assistant could manually adjust the size and appearance of the calibration target as well as its location and timing.

For users who have no experience with eye control it may be hard for them to understand what they are expected to do during calibration. Calibration can be a tedious process. For example, Fredric (in Figure 36.12) has a squint, which made it difficult for the eye tracker to recognize his eyes. A manual calibration was eventually achieved, with a lot of prompting and support from the staff at DART. At the second trial, he was unable to complete the calibration. It is assumed that the calibration process is not motivating enough—there should be pictures and sounds to look at to make it more interesting. Luckily, in his case, the default calibration worked reasonably well.

36.6.3 User's Abilities and Customized Software

36.6.3.1 Visual Representation and Feedback

Many of the participants had limitations in their visual and/or cognitive abilities. For them, it was essential that the visual representation and organization of the onscreen objects was adjustable to make them clearly visible and comprehensible (pictures, symbols, text, size, colors, and so on).

Proper visual and auditory feedback was found to be essential. For example, some people were not able to use dwell time to select objects if a visible cursor was shown, as the movement of the eye-driven cursor constantly distracted their eyes away from the target—but when feedback was given on the button itself and the cursor was hidden, they were able to dwell on it.

36.6.3.2 Progressive Trials

It was found to be helpful if gaze-driven activities were graded (easy/simple to difficult/complex) and carried out in many sessions over time. Some of the participants had not been able to access technology independently before, so any computer-based access method would require time for learning. Moving a cursor with eyes or using dwell time to select something (and avoiding a Midas touch at the same time) are new skills, even to people with perfect cognitive, literacy, and visual skills.

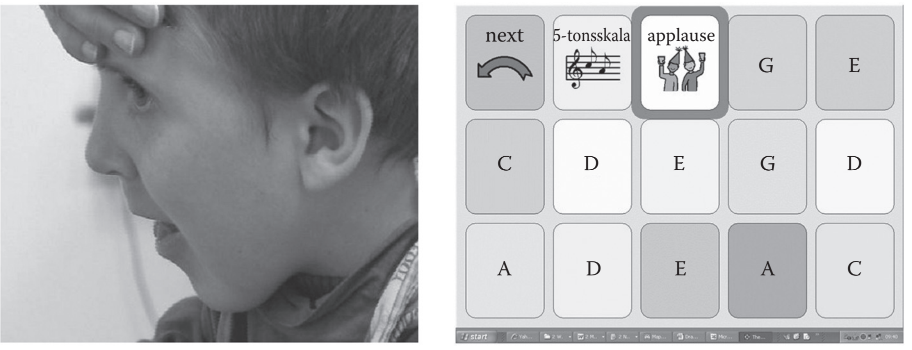

FIGURE 36.12 Fredrik (on the left), concentrating hard on playing guitar with the computer. A screen shot of a simple music playing application (on the right).

36.6.3.3 Introductory Activities with Immediate Positive Feedback

For some users with complex disabilities it was especially useful to try out eye control with very simple tasks, such as tasks where they could not fail. The easy start and immediate positive feedback gave a good basis for further trials with more demanding tasks. Playing music with the eyes was one such application that could be used in the initial trials: whenever the user was able to successfully dwell on a button, a musical sound was played. Many users found this activity rewarding and fun, and the success motivated them to try out more demanding tasks.

For example, Fredric, who suffered major brain damage when he was partially drowned, had not showed much interest or concentration on anything after the accident. Thus, it was not known how severe his brain damage was. He has no voluntary motor control, apart from his eyes. He was able to play music with his eyes and seemed to enjoy it a lot (Figure 36.12). It was the first time (after the accident) that any of his carers had seen him concentrate as hard and as long on anything.

36.6.3.4 User's Engagement and Motivation

The level of satisfaction and engagement gained from eye control appears to be relative to the level of disability. In particular, the adult participants with ALS, who were unable to speak or move any of their limbs, were particularly highly motivated to learn a new method of communication, and felt that eye control gave them hope when all other methods had failed.

Obviously, the tasks and the applications should be user focused; applications should be interesting and motivating to the specific user (considering their age, gender, interests, and so on). Being offered a possibility to independently access something that really interested the user may be the turning point in progress, as was true in Helen's case. By the age of nine, she had never been able to access any technology independently. All deliberate actions caused violent involuntary movement, even the effort of trying to speak causes spasm. However, it was found that her involuntary movement was not induced by eye control. Using eye control Helen is now able to write e-mails independently, in a relaxed, easy way. However, reaching the point where she could type by eye was not an easy or a quick process. Even though both her reading and spelling abilities were within her age range, the first trials with eye typing failed. She only selected random letters and showed no interest in it. She was more interested in stories that had been prepared for her, and she learned the basics of eye control by using her gaze to turn the pages of an onscreen book (Figure 36.13).

Nearly a year after the first trials, a personalized, eye-controlled e-mail utility was introduced to her. The possibility of independently writing e-mails was the turning point and made her really motivated to learn to eye type. Helen's eye-typing interface is illustrated in Figure 36.14. Because of involuntary head movement, the onscreen targets need to be fairly large. It takes two steps for her to type a letter, first selecting a group, and then the individual letter.

36.6.4 The KEE Approach: The Key for Successful Access to Eye Control Technology

Summarizing the experiences from the user trials, Donegan and Oosthuizen (2006) formulated the KEE concept for eye control and complex disabilities. It summarizes three key issues that enhance even the most complex users' chances of successful access to eye-control technology.

The KEE approach to trialing and implementing eye-control technology is:

- **K**nowledge-based, that is, founded on what is known of the user's physical and cognitive abilities
- **E**nd-user focused, that is, designed to meet the end-users' interests and needs
- **E**volutionary, that is, ready to change in relation to the end-user's response to eye-control technology and software provided

KEE is a tool for a successful assessment of whether or not eye control is—or can be made—accessible for a certain user. Following the KEE approach, "a different way of unlocking the door to eye control technology can be found for each user" (Donegan and Oosthuizen, 2006).

FIGURE 36.13 Helen learns to use her gaze to turn the page of an electronic storybook.

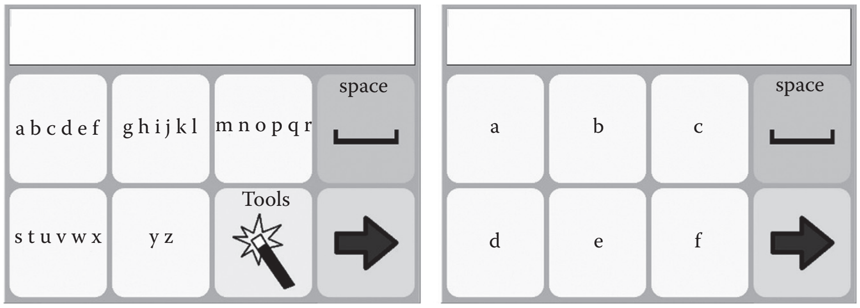

FIGURE 36.14 Helen's eye typing interface.

36.7 Conclusions

In Europe alone, the number of potential beneficiaries of eye-tracking technology amounts to several hundreds of thousands of people but, as yet, only a small number of these people are actually using eye control (Jordansen et al., 2005). For many of them, eye control is potentially the quickest, least tiring, and most reliable form of access to technology—by far.

The COGAIN user trials reported previously show that even if the first trial with eye control fails, it does not necessarily mean that eye-control technology is not suited for a certain user. With appropriate (or properly adjusted) hardware and software, eye-control technology can become accessible even to people with the most complex of disabilities.

Many of the potential users are already using special software for communication. If their condition deteriorates or if they for any other reason move to eye control, they should be able to continue using familiar programs. Existing applications should be made as eye-friendly as possible. There are a variety of applications especially directed at users with disabilities, such as environmental control applications, that would be highly beneficial for eye-control users if they were made eye-friendly.

The prices of the commercially available systems are still fairly high (thousands or tens of thousands of Euros). Even though current eye-tracking devices are reasonably accurate and fairly easy to use, they are not yet affordable to everybody. Several lower cost eye trackers are being developed (for examples of such low-cost systems, see, e.g., Corno et al., 2002; Fejtová et al., 2004; Li et al., 2006). However, to reduce the prices of commercial eye trackers, it is necessary to mainstream gaze interaction for a mass market (Hansen et al., 2005).

36.8 Future Directions

Using the eye as an input device is essential for disabled people who have no other means of controlling their environment. However, as has been discussed and demonstrated in this chapter, the eye is primarily a perceptual organ, and there are many problems in using the eye as a control medium. Therefore, one should not expect eye control to become an appealing option in mainstreaming applications, such as applications that are widely used by the general public. Instead of using the eyes as an explicit control medium, an application can make use of the information of the user's eye movements subtly in the background (being eye-aware) without disturbing the user's normal, natural viewing (Jacob, 1993).

Extending this concept, some of the most promising areas for eye-tracking applications are so-called attentive interfaces. Attentive user interfaces (Vertegaal, 2003) benefit from the information of the user's area of interest (AOI), and change the way information is displayed or the way the application behaves depending on the assumed attentive state of the user. By monitoring the user's eye movements the application knows more about the user's state and intentions, and is able to react in a more natural way, thus helping the user to work on the task instead of interacting with the computer (Nielsen, 1993).

Simply detecting the presence of eyes or recognizing eye contact can enhance the interaction substantially. EyePliances (Shell et al., 2003) are appliances and devices that respond to human eye contact. For example, an Attentive TV will automatically pause a movie when eye contact is lost, deducing nobody is watching the video, and "Look-To-Talk" devices (Shell et al., 2004) know when they are spoken to, for example, a lamp that reacts to the turn on/off command only when a person is looking at it. For a review of attentive applications, see, for example, Hyrskykari et al. (2005).

Gaming is another example of promising new areas for eye tracking. Adding gaze input can enhance the gaming experience and increase the immersion of a video game (Smith and Graham, 2006). Furthermore, eye interaction in games is fun and easy to learn, and perceived as natural and relaxed by the players (Jönsson, 2005). Gaze can be used in various ways, for example, to control the movement of the character or to aim in a first-person shooting game. Even though using gaze does not seem to be any faster or more efficient than the traditional controlling methods, it is not much worse, either (Isokoski and Martin, 2006). Results from user trials are promising, but more research is needed.

If eye trackers become more common, gaze input could also enhance interaction in standard desktop environments. For example, gaze could indicate the currently focused window in a desktop environment (Fono and Vertegaal, 2005), manual mouse pointing could be enhanced by automatically warping the cursor to or near the object the user is looking at (Zhai et al., 1999), or a web page could automatically scroll down (or up) following the gaze of the user reading it or searching information from it (Nakano et al., 2004). Gaze pointing combined with keyboard click for selection can be more efficient or at least comparable to using conventional mouse click—and is strongly preferred by most users (Kumar et al., 2007).

Eye control can offer great possibilities, but it is important to understand its limitations. As a mother of a young boy noted after an eye-control trial: "it was ironic that the more fun he had, the more he laughed and the more his eyes closed, making it impossible for the tracker to pick up his eyes."

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