Inventory of Electronic Mobility Aids for Persons with Visual Impairments: A Literature Review

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Abstract: This literature review of existing electronic mobility aids for persons who are visually impaired and recent developments in this field identified and classified 146 products, systems, and devices. The 21 that are currently available that can be used without environmental adaptation are described in functional terms.

Independent travel in unfamiliar environments is one of the major challenges that persons who are visually impaired (both those who are blind and those who have low vision) have to face in their daily lives (Marston & Golledge, 2003). The main problems include the lack of preview, knowledge of the environment, and access to information for orientation (Golledge, Marston, & Costanzo, 1997; Harper, Pettitt, & Goble, 2003; Helal, Moore, & Ramachandran, 2001). These problems frequently lead to less engagement in travel and activities outside the home, which affects productivity, employment, leisure and self-maintenance activities (Marston & Golledge, 2003; Walker & Lindsay, 2006), resulting in less participation in society.

To support their ability to move safely and purposefully, people who are visually impaired make use of several kinds of assistance, including sighted guides, white or long canes, and dog guides (Baldwin, 2003; Farmer & Smith, 1997; Zelek, Bromley, Asmar, & Thompson, 2003). Of the estimated 1.1 million persons who are blind in the United States, 10,000 own dog guides and 109,000 use white canes. Almost two-thirds of these cane users are younger than age 65, a noteworthy figure, since only one-third of all persons with visual impairments are younger than 65 (Demographics Update, 1994). Reliable data on the use of mobility devices in the Netherlands do not yet exist (Finsveen, Redeker, & Van Rooij, 2004). The white cane, in itself, however, is not sufficient for mobility; the user needs to acquire strategies for using it, which require intensive training by orientation and mobility (O&M) instructors. Furthermore, the white cane has a number of shortcomings, including an incomplete capacity for discrimination and protection against drop-offs; limited object-, surface-, and foot-placement previews; and no protection against collision

The authors thank the In Sight Society for funding this study within the In Sight program of ZonMw, the Netherlands organization for health research and development.

with obstacles on the upper part of the body (Farmer & Smith, 1997).

Electronic mobility aids were developed after World War II to augment the functionality of the conventional tools used for mobility by people with visual impairments or to replace them with new, comprehensive ones. In the 1960s, the first electronic mobility aids, such as Kay's Sonic Torch and Russell's Pathsounder, became commercially available. The introduction of the Global Positioning System (GPS) in the mid-1990s led to the emergence of a new type of electronic mobility aid to foster navigation. Innovative electronic mobility aids integrate technologies, which developed quickly in the mainstream consumer market, made electronic mobility aids affordable, small, lightweight, and portable. Standard devices, such as cell phones and personal digital assistants (PDAs), combined with infrared or sonar sensors and GPS navigation that make use of wireless connectivity and multiple input-output modalities, have promising potential for people who are visually impaired (Baldwin, 2003; Fruchterman, 2003; Gill, 2005).

The use of electronic mobility aids is not yet widespread. From the developers' point of view, this lack of use could be attributed to the fact that earlier devices did not fully meet the needs of persons with visual impairments, motivating the ongoing search for an ultimate solution. Little research on electronic mobility aids has dealt with questions related to the field of rehabilitation because most of the information is restricted to technical specifications (Farcy et al., 2006). Reports of users' experiences have thus far depicted the advantages of electronic mobility aids, described in general as increased safety, preview, mobility, and travel speed; a greater level of independence; the readiness to travel in unknown or unfamiliar environments; and the reduction of stress and discomfort. Many persons with visual impairments who have used electronic mobility aids have expressed that they are satisfied with their use (Blasch, Long, & Griffin-Shirley, 1989; Darling, Goodrich, & Wiley, 1977; Farcy et al., 2006).

As Strobel, Fossa, Panchura, Beaver, and Westbrook (2003) stated, "Assistive technology can mean a difference between gainful employment and unemployment; between success in the educational system and failure; and between integration into the community and segregation." For the effective application of electronic mobility aids in practice, users and involved professionals such as service providers need sound insights into the spectrum of existing devices and the functional capacities and abilities of these devices in daily life. This article addresses the first issue by reporting on a study of existing electronic mobility aids for persons who are visually impaired. After we conducted a broad survey of the variety of devices, systems, and recent developments in this field, we directed our attention to products that a person can use individually without environmental adaptations.

Method

We conducted a review of the literature from October 2007 to March 2008. In so doing, we consulted PubMed/MedLine, Embase, PsycINFO, and INSPEC/IEEE using combinations of the following terms and medical subject headings: *electronic travel aids, electronic mobility* *aids, electronic orientation aids, orientation, mobility, assistive technology, blindness, low vision, visually impaired persons,* and *self-help devices*. In addition, we inspected the records in two databases of assistive technology, Abledata and Eastin; extensively searched the Internet; searched reference lists of papers, articles in relevant scientific journals and conference proceedings; and reviewed product information in catalogs of distributors or at trade fairs and in user guides, handbooks, and training manuals. To obtain a complete impression of this kind of assistive technology, we included different sources that covered a wide range of content in relation to quantity and quality. No references were excluded on the basis of restrictions related to methodological quality.

At the same time, we searched the literature for major criteria that would permit all information to be summarized in a standardized way. Every system or device was entered into a database by specifying the following:

1. the name of the device
2. the type of device: for obstacle detection and orientation or navigation
3. the distinction between a primary or secondary device
4. the intended aim and main functionalities, such as avoiding obstacles; protecting the (upper) body; detecting objects, landmarks, and drop-offs; perceiving the environment; planning routes; guidance on routes; and finding points of interest.
5. the components
6. a description of the device, provided in functional and technical terms
7. the range of detection and the system's purpose for indoor or outdoor use
8. the user interface divided into different input and output modalities: tactile, haptic, or proprioceptive; audio; and optic or visual
9. the handling of a device
10. whether training in the device deals with whether good O&M skills are a prerequisite for safe use and if special training is needed
11. technical specifications, including size, weight, power supply, and warranty
12. any operational problems
13. availability
14. price
15. reference
16. distributor
17. illustration

This database offers an overview that allowed us to categorize the devices in many different ways, according to their intended purposes. For practical considerations regarding the application of electronic mobility aids, this study focused on electronic mobility aids that people who are visually impaired can use without environmental adaptations. The available electronic mobility aids were classified in two main categories: (1) devices that are aimed at obstacle detection and orientation and (2) those that are navigation systems. This categorization is comparable to the classification introduced by Petrie et al. (1997), who distinguished between micronavigation (avoiding obstacles and locating a clear path) and macronavigation (the ability to find one's way in a large, not immediate, environment).

Results

The results of this systematic review indicated 146 products, systems, and devices. The aforementioned classification identified 12 electronic mobility aids in the first category (obstacle detection and orientation) that are currently available: Bat "K" Sonar Cane (Bay Advanced Technologies, n.d.a, n.d.b, n.d.c; Kay, n.d.), Hand Guide Obstacle Detector (Independent Living Aids, n.d.), LaserCane (Hearmore, n.d.), Miniguide (GDP Research, n.d.a, n.d.b; Guide Dogs NSW/ACT, 2002), Mini-Radar (Bestpluton, n.d.b), Palmsonar PS231 (Takes Corporation, 2007a, 2007b, 2007c; Royal National Institute for the Blind, RNIB, 2007), Sonic Pathfinder (Heyes, n.d.a, n.d.b), Télétact (Damaschini, Legras, Leroux, & Farcy, 2005; Farcy et al., 2003, 2006), Tom-Pouce (Damaschini et al., 2005; Farcy et al., 2003, 2006), Ultra Body Guard (RTB, 2002, 2003), UltraCane (Hoyle & Dodds, 2006; Penrod, Corbett, & Blasch, 2005; Sound Foresight, n.d.), and Vistac Laser Long Cane (Vistac, 2004). The most important features of these devices are represented in Table 1 (Category 1); similarities and differences are discussed in the following paragraph, starting with their functionality as derived from their intended use.

All products are based on a comparable operating system. In a nutshell, a sensor unit emits an acoustic (ultrasound) or optic (laser or infrared) energy beam that is reflected by objects in its range. This range of detection depends on the number of sensors; their position; pointing and mounting; and the height, width, length, and shape of the energy beam covering diverse levels or planes. Received reflections are processed and transformed so that this information is made perceptible to the user who is visually impaired (Farmer & Smith, 1997). The use of all devices requires good O&M skills, which one can achieve only through extensive training. The amount of special or additional training that is needed to use an electronic mobility aid in this category efficiently varies considerably. It is closely linked with the intended functionality of the device, its range of detection, and its user interface, which are, of course, interrelated, and the ensuing quantity and kind of information that is presented. None of the available devices can substitute for a white cane or dog guide. Although six products are characterized as primary aids, they are categorized this way because they are integrated into, or mounted on, a white cane.

The aim of all these devices is to avoid obstacles, and hence to protect the (upper) body, through increased preview of the path ahead or detection of objects at different levels. If the avoidance of obstacles is the main functionality of the device, users are alerted solely to objects that they would otherwise collide with. This functionality is achieved in various ways, such as by the use of artificial intelligence to select relevant information about objects that would be encountered only during the next two seconds of travel, as with the Sonic Pathfinder, or by the range of detection being confined to a narrow, short beam, literally adding a second dimension to a white cane, as with the Vistac Laser Long Cane. For the detection of landmarks, a wider range of detection is useful. Actively searching for objects, landmarks, gaps, or doorways by scanning the surroundings is facilitated by handheld

Table 1
Electronic Mobility Aids: Category 1.

Device	Functionality	Interface	Mounting	Components	Range of detection	Handling
1. Bat "K" Sonar (Bay Advanced Technologies, n.d.a, n.d.b)	Acts as a vision substitute: spatial perception, recognition of objects, detection of landmarks and the distance and direction of objects, avoidance of obstacles (protection of the body), assists with alignment with the travel path (minimizes veering) and shorelining	Input: tactile (switches), output: audio (multiple tone complexes, referred to as "sound language"); the closer the object, the lower the pitch; the more distant the object, the higher the pitch	Handheld or attached to the handle of a cane	KASPA ultrasound headphones, rechargeable battery (lasts 1 day), 3 switches (volume up/down, range control)	Outdoors and indoors up to 6 meters (about 20 feet), long range: 5 meters (about 16 feet) with slower pulses, short range: 2 meters (about 6.5 feet) with faster pulses	Used with a white cane or dog guide. Best method: Hold the "K" Sonar at arm's length, with sonar and hand near the hip joint; correct the angle of the beam relative to the ground. Good O&M skills and special training required (basic training concepts)
2. Hand Guide Obstacle Detector (Independent Living Aids, n.d.; Penrod, Bauder, & Simmons, 2004)	Avoidance of obstacle to the front and above the wrist or waist (protection of the body); detection of the distance and direction of objects, landmarks, open doors, and hallways; assists with shorelining	Input: tactile (1 control switch), output: audio (chirp), or tactile (vibration); increased frequency as object comes closer	Handheld or clipped onto a pocket or belt	Infrared sensor, 2 AA batteries, pocket or belt clip, wrist strap, 1 switch (turn on or off, change output mode)	Outdoors and indoors; range of detection, 1.2 meters (about 4 feet)	Used with a white cane or dog guide; good O&M skills required
3. LaserCane (MEDmarketplace.com, Maxi-Aids; see Hearmore, n.d.)	Detection of the distance and direction of objects, landmarks, and drop-offs avoidance of obstacles (protection of the body)	Output: audio (audible tones) and tactile (vibrating stimulators under the index finger); audible tone turn-off option	Foldable white cane	Laser advanced technology, 2 AA rechargeable batteries, battery charger	Outdoors and indoors at 3 levels: head height, straight ahead, and drop-offs; ahead and to the sides	Used as a white cane; good O&M skills required; customized to the user's height

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Device	Functionality	Interface	Mounting	Components	Range of detection	Handling
4. Miniguide (GDP Research, n.d.a, n.d.b)	Avoidance of obstacles to the front and above the wrist or waist (protection of the body); detection of landmarks, the distance and direction of objects, and persons approaching one's personal space; assists with shorelining; allows user to actively search for objects, landmarks, gaps, and doors	Input: tactile (1 switch) output: tactile (vibration) or audio (sound feedback); the faster the signal, the nearer the object	Handheld	2 ultrasonic echolocation sensors, 1 switch, earphone socket, 123 type lithium battery (100–1,000 hours of use), wrist strap	Outdoors and indoors; 23 modes of use; basic settings: 4 meters (about 13 feet), 2 meters (about 6.5 feet), 1 meter (about 3 feet), 0.5 meter (about 1.6 feet), 8 meters (about 26 feet); range advanced settings 4 meters, 2 meters, 1 meter; gap- finding ranges; watchdog mode	Used with a white cane or dog guide, good O&M skills and special training required, detailed training package available, correct hand position
5. Mini-Radar [Bestpluton, n.d.b]	Mode 1: avoidance of obstacles (protection of the body); Mode 2: detection of landmarks, light, alignment with the travel path, and the distance of objects; optional: directional stability (device announces deviation from the path); minimizes veering (allowing one to cross in a straight line); optional: talking compass (device announces headed direction in 8 sectors); optional: GPS "Petit-Poucet"	Input: tactile (buttons to switch between the 2 modes and light detection) output: audio (spoken messages: "stop," "free way"/distance in feet or decimeters/daylight, dark, light in sight; optional: position compared with North, for example, "Cape 100," headed direction, such as "Northeast")	Carried around the neck or fixed to the belt	Ultrasound, earphone, 2 buttons	Outdoors and indoors range of detection, 3 meters (about 10 feet); width of beam, 60 centimeters (about 24 inches); height, 1.2 meters (about 4 feet)	Used with a white cane or dog guide; good O&M skills required

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Device	Functionality	Interface	Mounting	Components	Range of detection	Handling
6. Palmsonar PS 231 (RNIB, 2007; Takes Corporation, 2007a, 2007b, 2007c)	Avoidance of obstacles (protection of the body); detection of landmarks and the distance and direction of the closest object in the beam; assists in shorelining and active scanning	Input: tactile (1 switch button); output: tactile (vibration): the faster the signal, the nearer the object	Handheld, worn on the palm	Ultrasonic echolocation, CR 2032 battery, 1-switch button; wrist strap and palm band	Narrow horizontal beam 15 degrees to both sides; wide vertical beam 30 degrees up and down; different modes: 4 meters (about 13 feet), 1 meter (about 3 feet), 0.5 meter (about 1.6 feet), 0.3 meter (about 12 inches), 1.2 meters (about 4 feet), 1.4 meters (about 5 feet); 2-meter (about 6.5-foot) beam	Used with a white cane or dog guide; good O&M skills and special training required; daily practice is considered to be important (it may take 3 months to gain confidence and 1–2 years to continue to progress); 2 holes must be aligned vertically, so the narrow beam can be used horizontally
7. Sonic Pathfinder (Heyes, nd.a, nd.b)	Avoidance of obstacles to the front and above the waist (protection of the body); detection of the distance and direction of the nearest object only; in the absence of any such object, the device switches to its lower priority function and assists in shorelining	Input: output: audio (8 tones correspond to notes on the musical scale, analogous to distance: the nearer the object, the lower the tone; each tone represents a distance of 0.3 meters [about 12 inches]; direction is indicated by tones to the left or right ear or both ears)	Head mounted	Pulse-echo sonar system (3 receivers pointing left, right, and straight ahead; 2 transmitters), mounted on a headband, controlled by a microcomputer, "artificial intelligence" (to select relevant information only), earpieces	Outdoors, range of 2 seconds (information solely about objects that would be encountered during the next 2 seconds of travel); maximum range: 2.76–3.06 meters (about 9–10 feet); minimum range 0.0–0.75 meters (0–30 inches)	Used with a white cane or dog guide; good O&M skills and special training required (5 or 6 training sessions, spread over 2 or 3 days), training course (theoretical and practical sessions)

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Device	Functionality	Interface	Mounting	Components	Range of detection	Handling
8. Télétact (Damaschini et al., 2005; Farcy et al., 2003, 2006)	Recognition of objects (shapes), detection of landmarks and the distance and direction of obstacles, avoidance of obstacles (protection of the body), finds the best travel path	Input: Output: tactile (2 vibrating devices located under 2 different fingers: the 1st codes distances between 3 meters [about 10 feet] and 6 meters [about 20 feet] by discrete vibration between 1.5 meters [about 5 feet] and 3 meters by strong vibration; the 2nd codes distances less than 1.5 meters) or by audio (to 15 meters [about 49 feet]; 28 different musical notes correspond to 28 unequal distance intervals (shorter for short distances): the higher the tone, the shorter the distance; transcription of the profile of an obstacle into a "melody"	Usually clipped onto a white cane	Handheld laser telemeter	Outdoors and indoors up to a 6-meter (20-foot) range (tactile output) and up to a 15-meter (49-foot) range (audio output); beam is pointing	Users have to scan the environment; used with a white cane or dog guide; good O&M skills and special training required; users have to start with the Tom-Pouce and then continue with the tactile output version limited to the 6-meter range; 15-meter range only with audio output; requires users to develop a new cognitive process; users need to filter and interpret a great amount of information
9. Tom-Pouce (Farcy et al., 2003, 2006)	Avoidance of obstacles to the front and above the wrist or waist (protects the body)	Output: tactile (vibration located on the pinky finger)	Clipped onto a white cane	Infrared beams generated by collimated LEDs	Outdoors and indoors; 3 distances of detection: 0.5 meter (about 1.6 feet), 1.5 meters (about 5 feet), and 3 meters (about 10 feet); 20 degrees horizontal 50 degrees vertical; beam width: 0.6 meters–3 meters (about 24 inches to 10 feet)	Used with a white cane or dog guide; good O&M skills and special training required (10 to 20 sessions spread over 3–4 months)

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Device	Functionality	Interface	Mounting	Components	Range of detection	Handling
10. Ultra Body Guard (RTB, 2002, 2003, n.d.)	Avoidance of obstacles to the front and above the wrist or waist (protects the body); detection of landmarks, light, and the distance and direction of objects; assists with alignment to the travel path; provides for the storage of travel routes	Input: tactile (1 switch, 3 buttons); output: tactile (vibration; vibrating pin on the device or vibrating band worn on the neck or placed on the shoulder; the faster, the nearer the object) and audio (spoken information pedometer, musical tones light sensor, spoken compass directions; "left" or "right" directional stability)	Handheld or worn around the neck	Ultrasound, Microprocessor, talking compass, directional stability, pedometer with memory function, light sensor, speaker, switch and 3 buttons, 2 languages (English and German)	Outdoors and indoors, range of detection: 0.3 meters (about 12 inches) to 3.2 meters (about 10.5 feet); 15 degrees horizontal, 45 degrees vertical	Used with a white cane or dog guide; good O&M skills and special training required
11. UltraCane (Sound Foresight, n.d.a, n.d.b, n.d.c, n.d.d)	Avoidance of obstacles to the front and above the wrist or waist (protection of the body); detection of landmarks and the distance and direction of objects; aids in the alignment of the travel path and shorelining	Input: tactile (on or off or range switch);output: tactile (2 vibrating buttons: farthest away: feedback forward beam–the faster, the closer the object; closest to the body: feedback upper beam–obstacles at shoulder or head height, strong vibrations)	Mounted on a foldable white cane	2 ultrasound sensors; 2 vibrating buttons; 2 AA batteries, dry cell or rechargeable; wrist strap, on or off or range switch	2 ranges forward sensor: short, 2 meters (about 6.5 feet); long: 4 meters (about 13 feet); upper sensor: 1.5 meters (about 5 feet)	Used as a white cane; good O&M skills and special training required; training material or courses can be customized to a user's personal style and height; scanning to locate landmarks

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Device	Functionality	Interface	Mounting	Components	Range of detection	Handling
12. Vistac Laser Long Cane (Vistac, 2004, n.d.)	Avoids obstacles above the wrist or waist (protects the body); detects the direction of objects	Input: tactile (1 switch), output: tactile (vibration felt through the entire grip of the handle; continuous: warning of obstacles; intermittent: low battery or internal fault)	Mounted on a white cane	Laser, asymmetrical handle, on/off switch, 2 mignon rechargeable batteries (4 hours of continuous use)	Laser beam is narrow: width 30 degrees vertically, 5 millimeters (0.2 inches) horizontally, 1.4 meters (1.6 feet) ahead; adjustable distance setting	Used as a white cane, good O&M skills and special training (at least 1 hour to obtain the correct positioning and grip), simple yes or no information provided
13. CityCane (Kemper Hilfstechnik, 2008)	Makes a green traffic light audible to its user	Output: audio (audible signal)	Mounted on the handle of a foldable ergonomically designed cane	A foldable ergonomically designed cane with a shock absorber, color sensors, computer chip, and speaker	Outdoors; the color sensors have to be positioned directly in front of the traffic light	Used as a white cane; at traffic lights, the color sensors have to be positioned directly in front of the green traffic light; good O&M skills and special training (4-20 hours) required

devices, among them those that are mounted on a cane. Making use of their proprioceptive perception, persons who are visually impaired can determine the direction of an object by the pointing position of their upper extremity at the moment the device's output is perceived.

Other options to indicate the direction of objects are the transmission of audible signals to the left, right, or both ears or tactile signals to discernible points on the user's body. The distance of objects is made perceptible through knowledge of the range of detection, the varying frequency of audible or tactile signals (the faster the signals, the nearer the object), the corresponding pitch of sound, a scale of musical tones, or spoken messages (distance in feet or decimeters). Information on distant objects and cardinal directions help users align themselves to the path of travel and to minimize veering. To assist in shorelining (that is, traveling along a wall, fence, or hedge), a device needs to be able to detect objects along the sides. The LaserCane is the only device whose range covers the ground level and thus is capable of detecting drop-offs. The most comprehensive and complex information on the surrounding environment is offered by the Télétact, with its 15-meter-range audio output mode in the form of multiple tones, referred to as "melody," and by the Bat "K" Sonar, which is supposed to act as a substitute for vision. These devices can recognize not only distance and direction, but the characteristics of objects, such as their shape or surface.

The input modality of all devices is tactile: One or more switches can be used to turn the devices on or off, to change from one mode to another, or to control the volume of audio output. In some cases, the range of detection, as well as features of the cane, such as its length or tip, are adjustable and customizable to the individual user's needs.

According to its manufacturer, the CityCane (Kemper Hilfstechnik, 2008; Verein zur Förderung der Blindenbildung, 2006), whose only intended functionality is to make a green traffic light audible to its user, was launched at the Sight City trade fair in Frankfurt in 2008.

Several more aids in the same category are no longer available: LaserCane, Model N 2000 (Abledata, 2008); Mowat Sensor-MS01(Abledata, 2008); N-8 laser cane (Abledata, 2008); Nottingham Obstacle Detector (Borenstein & Ulrich, 1997); Oscar: Obstacle Scan and Report (Abledata, 2008); Pathsounder (Abledata, 2008); Polaron (Abledata, 2008); Sensory 6 (Abledata, 2008); Sherpa-I (Slechtziend.nl, 2007; iRv Hulpmiddelen Wijzer, n.d.); Sonicguide (Abledata, 2008; Bay Advanced Technologies, n.d.c; Zabonne, 2006); Walkmate (KOC Vlibank, 2005); and Wheelchair Pathfinder (Abledata, 2008).

We found nine available electronic mobility aids, aimed at navigation, that people who are visually impaired can use individually, which means that no environmental adaptations are needed: Blind Navigator (Bestpluton, n.d.a), BrailleNote GPS and VoiceNote GPS (Abledata, 2008; Greenberg & Kuns, 2008; HumanWare, n.d.a; Sendero Group, n.d.a), Géotact (Farcy et al., 2006), GPS Petit-Poucet GRAND RAID (Bestpluton, n.d.a), Loadstone GPS (Loadstone GPS Team, n.d.a, n.d.b), PAC Mate + Street Talk (Freedom Scientific, 2005, n.d.), Trekker (HumanWare, n.d.b), Wayfinder

Access (Wayfinder, n.d.a, n.d.b), and Way To Go (Sendero Group, n.d.b, n.d.c). BrailleNote and VoiceNote GPS are also called Sendero GPS. For an overview of these devices, see Table 2 (Category 2).

All these products, except Way To Go, operate with a GPS, which was developed by the U.S. Department of Defense as a precision-navigation and location-information tool for military purposes. Receiving precisely timed specific electronic data signals from at least 3 of 24 orbiting satellites, GPS calculates the exact position expressed in geographic coordinates by triangulation. Transformed and combined with additional information, this technology can help users who are visually impaired travel independently (Dusling & Uslan, 2002; Farmer & Smith, 1997; Van den Breede & Engelen, 2004).

Table 2 reveals three different ways in which users can travel independently with the devices. The first relies on digital maps and databases, providing detailed navigation information on street names and addresses and information on intersections, waypoints, points of interest, distance, direction, time, and speed of travel. The main functionalities are route planning and route guidance, based on automatically created routes, information about the user's current location or position, and exploration of the environment. The second uses databases only to generate routes by loading certain points from a list of checkpoints that the person who is visually impaired is guided along to his or her destination, as is done with Loadstone GPS.

The third functions without digital maps or databases, and users have to create routes themselves. Personal announcements of street names, waypoints, individual points of interest, or any other remarks, referred to as "vocal landmarks," are recorded, together with GPS-based electronic waypoints while traveling a route for the first time with a sighted guide. Stored routes offer route guidance through spoken advice en route, but can also be explored virtually (as with the GPS Petit-Poucet GRAND RAID). With most comprehensive devices, users can choose among all these possibilities as different modes or functionalities. To improve the travel skills of persons who are visually impaired, Géotact provides minimal information only. Users are guided through a few points—four on a 2-kilometer (about 1.2-mile) route are considered to be sufficient—and have to determine a suitable path on their own. Way To Go, whose main functionality is to present extensive map material in an accessible way, differs from the other systems in that it does not provide any route guidance. With regard to the hardware components of the products that are currently available, one can distinguish among

- those that are designed especially for users who are visually impaired: BrailleNote or VoiceNote and PAC Mate accessible pocket PC
- systems that make use of mainstream hardware, such as pocket PCs, PDAs, or mobile (cell) phones running Symbian (Series 60), combined with access software, and
- stand-alone products like GPS Petit-Poucet GRAND RAID, which is also obtainable as an additional function of one Category 1 device, the Mini-Radar.

All these devices are secondary aids, which implies that they have to be used in conjunction with a white cane or a dog

Table 2
Electronic Mobility Aids: Category 2.

Device	Functionality	Modes	Information	Interface	Routes	Components
1. Blind Navigator (Bestpluton, n.d.a)	Provides route planning and. route guidance through spoken advice; searches points of interest; user can walk around, and street names are announced (free mode); stores recorded user-created routes; allows for virtual exploration of a route; provides additional functions of a PDA	Pedestrian mode vehicular mode free mode	Street names distance, distance covered, remaining distance direction speed of travel, time, date points of interest user created points of interest spoken advice like "towards the left", "towards the right", "go straight", "U-turn" etc.	Input: tactile (buttons) and audio (speech) output: audio (speech) customizable: verbosity (amount of information provided)	automatically created created by the user	PDA (pocket-PC) GPS receiver (EGNOS compatible) speaker microphone access software PDA maps (all European countries) database
2. BrailleNote GPS and VoiceNote GPS (Sendero GPS) (HumanWare, n.d.a; Sendero Group, n.d.a)	Plans route to a destination (address, point of interest, virtual explore position, or latitude & longitude); provides route guidance, current location or position ("Where am I"?), user points of interest; allows user to explore surroundings and to explore locations without being there (virtual explore mode); records GPS information while traveling, so user can play it back (GPS replay files); records messages; has odometer and additional functions of the BrailleNote notetaker	Navigation mode; different route-following modes: in Turns-Only or Detailed Waypoint mode, different LookAround modes: automatic, multiple repeat, and manual; virtual explore mode	More than 13 million points of interest are stored in the database: user-created points of interest; street names; approximate addresses; distance (and heading direction) to the next intersection; current waypoint; next turn or destination; speed of travel; latitude, longitude, altitude; GPS time, date; stopwatch; orientation heading (clock face or left or right distance heading); compass heading (4 directions, given after clock face or left or right position announcement) and compass heading in degrees	Input: tactile (9-key braille keyboard or QWERTY computer-style keyboard); output: tactile (18- or 32-cell refreshable braille display) and audio (speech, sounds to signal different warnings), audio output alone (VoiceNote GPS); customizable: volume; speed and pitch control; sound cues (can also be turned off); interval in seconds for repeating automatic announcements of heading and distance to current waypoint, next turn, or destination	Automatically created; manually created (if user prefers different route or maps are unavailable) pedestrian routes, vehicular routes; GPS replay files; routes can be used in conjunction with the LookAround information; routes can be customized, saved, edited, and exchanged with other users	BrailleNote notetaker; built-in speaker; GPS receiver; Sendero GPS software, version 4.22; maps; database; carrying case

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Device	Functionality	Modes	Information	Interface	Routes	Components
3. Géotact (Farcy et al., 2006)	Provides minimum route guidance; users have to decide on their own how to travel between 2 points (intended to foster users' O&M skills); has several features for entering points from an address, the facility to use Google Earth (for example, to reach a point without an address), and the facility to register personal points		Has a restricted amount of information: does not indicate whether there is a direct path between 2 points; 4 points on a 2-kilometer (1.2-mile) route are considered to be sufficient; distance (in meters) and direction (system of the clock) to the next point are given	Output: audio (speech) only on request	Pedestrian routes	G PS system, inertial sensor to reduce the effects of degradation of GPS information at urban canyons
4. GPS Petit-Poucet GRAND RAID (Bestpluton n.d.a)	Stores recorded user-created routes; provides route guidance through spoken advice; allows for virtual exploration of a route: user can listen to the details of a route without traveling it; has additional functions of the Mini-Radar	Pedestrian record mode, vehicular record mode, guiding mode, go-on mode, go-back mode, step-to-step mode (virtual exploration)	Spoken advice like "toward the left," "toward the right," "go straight," and "U-turn"; additional: time, time spent, distance covered, remaining distance, speed, direction, altitude, date	Input: audio (speech "vocal landmarks") and tactile (2 buttons: "menu" and "validation"); output: audio (speech)	Created by the user with assistance of a sighted guide, pedestrian routes, vehicular routes; many routes can be stored: up to 3,500 kilometers (about 2,175 miles) with 1 point every 2 meters (about 6.5 feet) (pedestrian routes) or up to 25,000 kilometers (about 15,534 miles) (vehicular routes)	GPS receiver, 2 buttons, power supply: 4 batteries AAA R3 (100–200 hours of use) or AA R6 (200–400 hours of use); also available as an optional function of the Mini-Radar

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Table 2
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Device	Functionality	Modes	Information	Interface	Routes	Components
5. Loadstone GPS (Loadstone GPS team, n.d.a, n.d.b)	Provides route guidance by guiding the user from point to point on a manually created route (heading, direction of travel, checkpoint, and distance to that point), provides information about the current environment; gives user the ability to explore and interact with points in a maplike fashion; user can virtually navigate from point to point, find a certain point by entering search criteria; shows a list of points surrounding the current position and the starting point	Navigation mode and exploration mode	Provides the closest point to the current position in any direction, speed, direction and altitude, longitude and latitude coordinates; has an alphanumeric label to the coordinates in the form of a "point"; provides heading in degrees, 12/8 cardinal compass directions, or clock face	Input: tactile (mobile phone keypad); output: blind user: audio (speech, screen reader); user with low vision: optical (display and magnifier)	Manually created routes only; user has to add significant points on a route every 15 meters (about 49 feet); user can also load a point from a list of checkpoints; points can be imported to and exported from the user's database	Mobile (cell) phone running Symbian (Series 60), access software (screen reader or magnifier), Bluetooth GPS receiver, Loadstone GPS software, Loadstone database; optional: USB Bluetooth dongle, Bluetooth headset, multimedia card (MMC) reader, high-capacity MMC
6. PAC Mate and StreetTalk (Freedom Scientific, 2005, n.d.)	Provides current location or position ("Where am I"?), route planning, route guidance; allows user to explore the environment ("What is around me?")	Planner mode: to create a route or find points of interest when the GPS is not available; navigation mode: to alert the traveler when to make turns along the created route	Has millions of points of interest: personal points of interest; street addresses; directions: "turn left" or "turn right"; provides cardinal directions only at the start, bearing, speed, distance to the destination, distance traveled; GPS information: latitude, longitude, and time	Input: tactile (braille Perkins-style keyboard or QWERTY laptop-style keyboard); shortcut keystrokes; output: tactile (20 or 40 cells of refreshable braille) and audio (speech) or audio (speech) only	Pedestrian routes, vehicular routes, "breadcrumb" routes (recording of user's position every 3 seconds or every 3 meters (about 10 feet); not in unmapped areas, based on Destinator's map data); saved turn-by-turn directions; custom routes designed on the go; routes can be printed, embossed, beamed, or e-mailed to other users	PAC Mate QX or BX; accessible Pocket PC; Bluetooth GPS receiver; StreetTalk, version 2.0 (accessibility interface to the Destinator application—Destinator is a satellite-based navigation system); maps; database

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Table 2
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Device	Functionality	Modes	Information	Interface	Routes	Components
7. Trekker (HumanWare, 2008, n.d.a, n.d.b, n.d.c)	Provides route guidance, route planning, current location or position ("Where am I?"); allows user to explore the outdoor environment ("What is around me?"), detect intersections and points of interest, and search points of interest (by distance or by address); has additional functions of the Maestro (optional)	Pedestrian mode, motorized mode (less detailed information), and free mode (used in unmapped areas)	More than 1,5 million points of interest: personal points of interest, street names, street mapping, intersections, crossings; announces whether the user is On Route; provides heading direction (such as North or Northeast), direction to take (go right, left, go straight, or go back), distance, route information (name, distance remaining and traveled, length), speed, latitude, longitude, altitude, GPS status	Input: tactile (mobile phone keyboard can be configured as a braille keypad); output: audio (speech) automatically announced on request; customizable: verbosity (detailed information or summary), voice rate of speech, uncontracted or contracted braille	Pedestrian routes and vehicular routes	PDA (Pocket PC), Bluetooth GPS receiver, Royal Tek RBT 2100, clip-on case, external speaker with audio cable, Power Splitter, strap, travel bag GPS maps on CD and storage card, database, microphone
8. Wayfinder Access (Wayfinder, n.d.a, n.d.b)	Allows for continuous exploration of the current environment; provides current location and position ("Where am I?"), route guidance (navigation), map exploration		Intersections, points of interest, more than 20 million locations, provides door-to-door voice directions, navigation instructions (clock-based format or compass-based format with 8 directions)	Input: tactile (mobile phone numeric keypad); output: audio (speech); optional: braille input and output; customizable: volume of the voice instructions, number of voice instructions given during navigation, backlight settings, language, amount of information (detailed or brief)	Pedestrian routes and vehicular routes (by passenger car or taxi); routes can be loaded, saved, played, or erased	Mobile (cell) phone running Symbian (Series 60); Bluetooth GPS receiver; Wayfinder Access software, version 1..24 or higher; compatible text-to-speech application Nuance Talks and Mobile Speak; mobile phone Internet connection; maps; database

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Table 2
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Device	Functionality	Modes	Information	Interface	Routes	Components
9. Way To Go (Sendero Group, n.d.b, n.d.c)	Provides the equivalent of print maps in accessible formats; allows for the virtual exploration and understanding of the user's surroundings; provides a mental picture of the environment, route planning, points of interest; additional functions: records messages, has an odometer	Virtual Explore, Routes, points of interest	More than 15 million points of interest; provides distance and direction to a business, street address, or intersection; orientation heading (clock face or left or right); distance heading; compass heading (4 directions, given after the clock face or left or right position is announced); compass heading in degrees	Input: tactile (9-key braille keyboard or QWERTY computer-style keyboard); output: tactile (18- or 32-cell refreshable braille display) and audio (speech); customizable: sound cues (can also be turned off)	Automatically created or manually created pedestrian routes and vehicular routes	BrailleNote or VoiceNote, mPower, Way To Go software, maps on DVD, database
10. Trekker Breeze (HumanWare, 2008)	Provides route guidance, navigational assistance for visual impaired users who are not comfortable with computers and screen readers		Street names, intersections, reference landmarks, turn-by-turn instructions	Output: audio (speech)	Created by the user with the assistance of a sighted guide; pedestrian routes and vehicular routes; routes can be recorded, previewed, or activated for future use	

guide. Evidently, the efficient use of these devices requires not only good O&M skills, but, with the exception of GPS Petit-Poucet GRAND RAID, the ability to use mobile phones and computers. Because of the limited available information about Géotact, it is not possible to provide more details on its components and mode of operation.

One product—Trekker Breeze (HumanWare, 2008)—is advertised as being commercially available in summer 2008. As may be concluded from the brief description of the product that was provided, its functionality seems comparable to that of GPS Petit-Poucet GRAND RAID, which uses recorded user-created routes. Atlas Speaks (Abledata, 2008); On Track (Abledata, 2008); and Strider (Abledata, 2008), which used the Atlas Speaks talking map program, are no longer available.

The remaining 107 systems and devices are not described in detail here, since they cannot actually be used for one or both of the following reasons: They are prototypes or are not meant for personal or individual use in the sense of being constructed for residential settings or relying on environmental adaptations. To give at least a brief impression, recent developments are outlined next.

One group of prototypes could be characterized as variations on devices of Category 1, aimed at obstacle detection and orientation. Research has dealt primarily with different input and output modalities; besides the use of ultrasound, infrared, and laser, other operating systems for the perception of the surrounding environment have been tested. The second group addresses the shortcomings of the available GPS systems of Category 2, aimed at navigation, which could be summed up in general as being applicable only outdoors; however, they have limited accuracy and lose track because of urban canyons, trees, or weather conditions. Still other devices combine the functionalities of both categories, in some cases providing additional support for physical mobility. Further advancements have included products that focus on intuitive use, minimizing the amount of special or additional training; products that are tailored to individual needs, offering different and customizable input and output modalities; and modular devices with diverse combinations of functionalities.

At present, the use of available electronic mobility aids requires good O&M skills. Because of the increasing number of persons who become visually impaired in old age or who also have cognitive impairments, the development of electronic mobility aids has focused on devices that can be used by older persons who do not have good O&M skills and will probably have difficulty learning them through extensive, time-consuming, and demanding training.

The last group covers a wide range of systems that are based on environmental adaptations. Within these environmental adaptations, two functionalities can be distinguished: providing guidance on predetermined routes or making information about the surroundings accessible to users who are visually impaired. This information is not restricted to assistance with O&M, wayfinding, or route guidance; related activities of daily living, such as the use of public transportation or grocery shopping, are considered, too.

Discussion

In the first phase of the review, we emphasized a general overview of the variety of electronic mobility aids for persons who are visually impaired. Our intent was to compile a full list of products, systems, and devices, so we sought data widely and collected and summarized all kinds of information, as was described in the Method section. With regard to the available devices, not all information was published in the scientific literature. Some information on products was confined to secondary sources, and a number of Internet sites that we referred to are no longer retrievable. Several products that were no longer available were retained in the Abledata database for reference. A few references could not be taken into account because they were presented in languages that we did not know.

In the second phase of the review, we focused on electronic mobility aids that could be used by a person who is visually impaired without environmental adaptation. Detailed and valuable information on these devices is provided in their user guides, handbooks, training manuals, and the like, leading to a better understanding of the functionality of the devices than would be obtained from studying the product information alone. Since these sources were sometimes not (electronically) published, we contacted distributors, manufacturers, and developers by telephone or e-mail. This additional step was also necessary for the proper selection of products, since information on the availability of products, as provided by various sources, turned out not to be always reliable or up to date. Nevertheless, the amount and detail of information were different for different products. When one looks at the results and presentation of important features in Tables 1 and 2, one should keep in mind that these findings stem solely from a review of the literature; we neither tested nor evaluated these products.

Conclusion

The inventory of electronic mobility aids encompassed 146 systems, products, and devices. With regard to the application of electronic mobility aids in practice, we focused on products that people who are visually impaired can actually use without environmental adaptations. A process of selection and classification resulted in the systematic functional description of 21 currently available electronic mobility aids, 12 in Category 1, aimed at obstacle detection and orientation, and 9 in Category 2, aimed at navigation. Two more devices were identified that will be available soon. Presented as practical guidelines and information on products, these results can offer relevant knowledge for users and service providers. Thus, they can contribute to the matching of individual users with the most appropriate assistive devices. In addition to awareness of the range of available devices, more insights are needed into the way the devices provide functional assistance in daily life. Future research should therefore assess the functionality of electronic mobility aids and their effects on the mobility of their users.

Reviewing all the products, systems, and devices that we entered into the database allowed us to summarize recent developments in the field of assistive technology in the Results section. The different groups that we mentioned show not only various trends in research, but a great number of different products or solutions within each category. It is remarkable that many products, particularly those in Category 1, are no longer available and that many systems and devices are prototypes that are either in development or failed to enter the market. Further research should investigate the reasons for this situation. Moreover, the historical development and trends of the applied technologies should be analyzed. Functions and capabilities, as well as the inherent advantages and disadvantages, of different technologies should be described with regard to the consequences for the functionality of the assistive devices. The continuous development of systems can be regarded as a strong indicator of the potential of the field of assistive technology, and future research could well support further advancements.

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