Gesture, Signing and Tracking

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1. Introduction

There is a wide and growing range of physical input devices for (or integrated into) PCs, mobile phones, games consoles or other devices that depend on tracking bodily gestures, which promise to make computing, environmental control and mobility more accessible, facilitating alternative and augmentative communication or supporting rehabilitation.

This is a particularly exciting time for innovators of assistive technologies since gestural input is fast becoming mainstream, with consumer level eye-tracking and virtual reality being marketed for games and leisure, taking it out of the research and development setting and into the homes of the general population, which is reducing the price barrier and encouraging application developers. A variety of motion tracking systems are already present in well-known games consoles, and their capabilities continue to improve. Furthermore, contemporary mobile devices are packed with features that can detect motion and touch.

This chapter takes a holistic approach to gesture based systems, focussing on evaluation techniques and, where these exist, identification of relevant standards, and a summary of some best practice offered in the literature for their application in assistive technology assessment. Examples that illustrate these techniques are presented as summaries of case studies from the literature.

2. Physical input devices and gestural interfaces

When considering the body as an input device, areas of anatomy commonly seen in assistive technologies that use gestural interaction include one or more of the following: upper limb (shoulder, arm, hand), head (eye, mouth/tongue, forehead) and to a lesser extent lower limb (leg, foot) and trunk.

Devices that afford gestural input detection include mice and trackballs, styli, joysticks, eye-trackers (including glasses), light-sensors (visible or infra-red, from a video display or other light source), feature or object trackers (with images from a single visible, infra-red or thermal camera, stereo cameras or depth sensor), three or six degrees-of-freedom in-air trackers (as typically found in virtual reality systems) which may include a glove or vest, touchscreen interfaces of smartphones etc., pressure or force sensors, and devices that use near-distance hover detection, ranging or intersection techniques. Accelerometers, rotation sensors and gyroscopes embedded in smartphones and wearables (smartwatches, wristbands, clothes, shoes) also readily detect motion. Recent innovations being developed for mobile devices and wearables include miniaturised ultrasound or radar transducers. Some input devices include detection of single clicks/taps or multiple touch events in addition to motion.

A full taxonomy of gestural interfaces is therefore quite complex, but it can readily be seen that the most common interactions can be roughly divided in into (a) 2D point-and-click or in-air gestural inputs that result in a stream of (x,y) screen coordinates (b) fully 3D gesture tracking that results in a sequence of location, acceleration or rotation coordinates, alone or together with 1D clicks, taps or touches and (c) systems that capture 1D information such as finger flexion from a glove. To this can be added interactions that employ enhanced features of single contacts such as pressure sensing, and those that employ multiple contacts e.g., from two or more touch, hover or intersection events. Some camera-based techniques may use image/object recognition algorithms to extract 2D or 3D shape and optical properties such as colour e.g., extraction of skin colour as an image segmentation technique in sign-language recognition algorithms. Similarly, signal processing techniques are used to extract gesture information from ultrasound and radar sensors.

A basic illustration of a range of devices is shown in Table 1. The products listed are mainly chosen as either examples of consumer products or innovative assistive technologies that have been subject to evaluation in the academic literature. It is not intended to be exhaustive and new devices and products are continually emerging. Some newer technologies being investigated for use in gestural interaction are cited at the end of this chapter.

Table 1. Examples of physical input devices and AT for gestural interaction

Device	**Interaction(s)**	**Coordinate system**	**Events**	**Enhancements**	**Example products & systems**
Mouse	Point and Click	2D	Mouse up/down buttons	Scroll wheel	Generic mouse, trackball etc.
Touch pad or screen	Point and sense	2D	Touch, Double touch	Hover, pressure	Generic mobile touchscreen, Gest Rest (Carrington et al., 2016)
Camera(s)	Image/object detection	2D/3D	Video frame capture	Depth, recognition, thermal imaging	Kinect (Standen et al., 2015), Leap motion (Smeragliuolo, Hill, Disla, & Putrino, 2016), Camera Mouse (Betke, Gips, & Fleming, 2002),
Eye-tracker	Gaze detection	2D/3D	Eye presence, stream of gaze fixation points	Head facing direction, glasses	Tobii products e.g., Dynavox, Pro Glasses
In-air tracker	Anatomical point or feature location	3D + rotation on each axis	Continuous data stream from multiple locations	Glove	Polhemus products, GesRec3D (Craven & Curtis, 2003)
Glove	Hand pose and finger motion	1D/3D	Data from multiple digits	3D in-air tracker e.g., for hand location	Various products and systems
Vest/ jacket	Trunk and shoulder motion	1D/3D	Data from accelerometer	Biosensing	Various products and systems

2.1 Standards for principles and requirements

As introduced earlier in this volume (Chapter 15), ISO 9241 is a multi-part standard from the International Organization for Standardization (ISO) covering the ergonomics of human-computer interaction. One part of the standard ISO 9241-400:2007 ‘Principles and requirements for physical input devices’ covers the more common devices mentioned above and also includes the ergonomics of keyboards and legacy devices such as lightpens. The standard differentiates the following specific aspects of physical input device ergonomics in more or less the same way as in the above introduction: bodily action (hand and finger, foot, mouth, speech, eye, motion); basic types of task, called task primitives (code entry, pointing, dragging, selecting, tracing); degrees of freedom (single, double, three); property sensed (pressure, motion, position, sound, optical properties).

ISO 9241-400:2007 also lists a set of design requirements in the terms of appropriateness of the device for its intended user and the tasks to be performed in the intended environment, operability (obviousness, predictability, consistency, user compatibility & feedback), controllability (responsiveness, non-interference, reliability and adequacy of device access, control access) and biomechanical load (posture, effort).

A related standard ISO 9241-410:2008 considers design criteria for the different types of physical input devices.

Depending on the device, to ensure good usability, some criteria address design of the externals and internals of the hardware and software, whereas others are about the device's relationship to the environment. An example of the former is the requirement to provide a hardware or software 'lock' for a mouse or other 2D input device to facilitate dragging, tracing or freehand input so that the user does not need to hold down a button. An example of the latter is the requirement to make it possible for user to anchor their limb i.e., to create a stable relationship between a hand and the point of action e.g., rest a palm on a table. We can note that in assistive technologies an input device may itself be anchored e.g., joystick on a motorised wheelchair. Also for gestural input, it will be necessary to consider the potential for impairment of usability due to poor arrangement of equipment with respect to the user's body e.g., occlusion of a sensor such as blocking a camera's field of view.

Evaluation of performance based on these criteria must then be developed for the particular devices, users and environments in question.

2.2 Holistic approach to gestural interaction

For the purpose of evaluating assistive, augmentative or rehabilitation technologies, a holistic approach to ATA for gestural input devices and tracking technologies will be explored. This approach is hopefully justified by the highlighting of some generally similar features of the technologies whilst describing some key differences.

One similarity across gestural input devices is the acquisition of 2D or 3D coordinates to describe the motion or to record contact points. A motion data stream may be a more or less smooth continuous transition or one that is more discrete, such as with eye-tracking where the eye's direction of gaze moves rapidly from one point to the next, known as saccades. Specific motor impairments also affect an individual's smoothness of motion. Tapping events may have 2D coordinates (such as mouse clicks or touches) or else the act of clicking is simply recorded (a 1D gesture). Magnitude of force/pressure and angles of flexion/extension are other examples of 1D data collection of general relevance in gesture interaction. If information about ordering of input or speed is required by the software, timing data or sample number will also be recorded.

Then, the individual's continuous motion must be segmented i.e., split up to determine the end of the gesture. Segmentation of a gesture coordinate stream will be made explicitly or implicitly by the user's action or else must be determined by an algorithm. For example, if a click event is used to make a selection after motion (such as point-and-click), then segmentation of the preceding motion is being made implicitly by the user's clicking action. Alternatively, a 'reserved action' can be built into the system such as the use of 'pigtail' gesture to end a stroke, as used in Scriboli, an early Microsoft pen interface (see Wigdor and Wixon 2011, p.99).

For interfaces that do not use explicit selection at the end of a physical movement, the 'Midas Touch problem' (Jacob, 1991) must always be addressed i.e. was the user's action intentional or not with respect to the interaction task in question? To avoid this problem, isolation of intended action can be achieved through the use of a period of 'dwell time', where the user must remain still at the end of the gesture. For example, when using an eye-tracker with dwell time, the user fixes their gaze on an object for a second or so in order to select it, whereas shorter glances are ignored as selection events. Setting the dwell duration is critical as it must be long enough to avoid false positives but not so long as to slow down the interaction. The user must also understand and get used to the technique.

Segmentation may instead be dwell-free and integrated into a recogniser, such as in continuous online recognition systems e.g., eye-typing or sign language recognition where there is enough information in the gesture set to enable the system to ignore unintended gestures and distinguish all intended ones. Dwell-free methods may also involve predicting the trajectory and classifying the gesture before it is finished, to increase production speed. Some gesture recognition systems use a combination of method for segmentation e.g., dwell/low velocity thresholds together with pattern recognition techniques (Craven & Curtis, 2003).

Alternatively, a 'reserved clutch' can be employed whereby a gesture is considered to be intentional only when the clutch is engaged e.g., use of a 'pinch' hand pose where a gesture is only recorded when finger and thumb are together (Wigdor and Wixon 2011, p.100). Another example of this is the two-step gaze interaction in Tobii products e.g., Dynavox PCEye Go. One further solution to the Midas Touch problem is to use a multi-modal interface e.g., gesture combined with speech where the action from gesturing is gated by a speech command or vice-versa (Wigdor and Wixon 2011, p.101).

Visual acuity is of particular relevance for accessibility of touchscreens. In a recent research paper, Luthra et al. (2015) considered the accessibility of gestural touch interaction in smartphone screen readers such as Voiceover in iOS and Talkback in Android by blind and visually impaired users. The authors offered insights into the forms of gestures that cause problems such as closed shapes and those with strictly defined angles.

3. Functional evaluation of physical input devices

3.1 Standard for functional evaluation

The technical specification ISO/TS 9241-411:2014 'Evaluation methods for the design of physical input devices' provides a good basis for functional assessment of gestural input for assistive technologies (and we can note that it also covers evaluation of keyboards, although this is not considered here).

Measurement of task precision in this specification is similar for mice, trackballs and other 2D input devices and relates to defined interaction tasks. Task primitives in the specification include the following: movement along one or two perpendicular axes or at any angle; feedback and prompting such as showing the mouse cursor or providing visual, auditory or tactile feedback when a target is hit; and target acquisition, either manual e.g., mouse clicking, or automatic e.g., eye-tracker using dwell time.

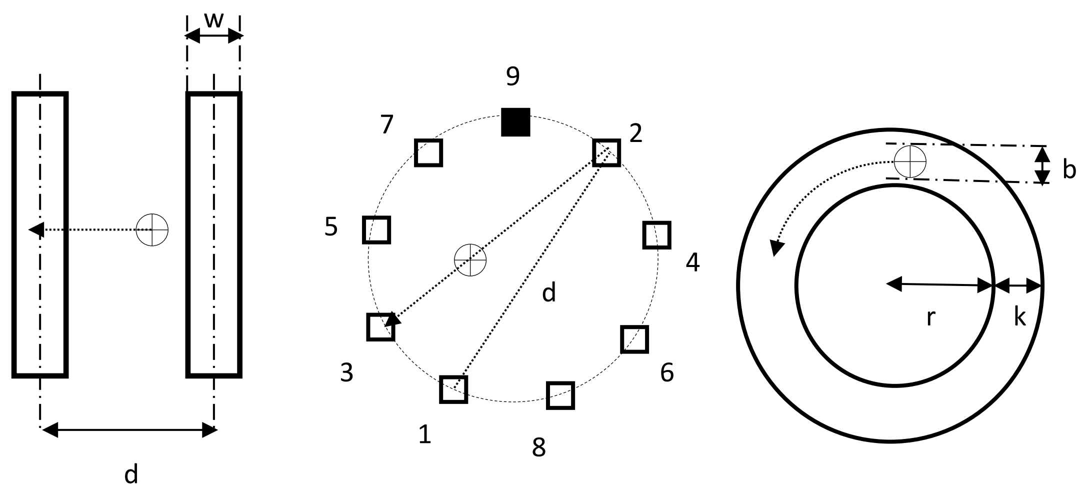

Figure 1. Example input tasks: single directional tapping, multi-directional tapping and tracing (adapted from ISO/TS 9241-411:2014).

To evaluate an input device on different tasks, effective index of difficulty I_{De} (in units of bits) is first defined as $\log_2 [(d + w_e)/w_e]$ for selection, pointing or dragging tasks or d / w_e for tracing tasks, where d is the distance to the target and w_e is the effective target width (which is a derivation of the actual feature width). Task precision is divided into four levels of difficulty C1-C4 where the highest is $I_{De} > 6$ and the lowest $I_{De} < 3$ such that any test should ideally include a range of difficulties.

Figure 1 shows three input evaluation tasks; single directional tapping, multiple directional tapping, and the tracing task. For the single directional tapping task the user moves along one axis and selects targets of width w separated by a distance d, repeated 25 times. The difficulty index is as defined above. For the multi-directional tapping task, the clicks are made across a circle, as close to the diagonal as possible, selecting the numbered targets in turn. The tracing task involves moving an object 360^o between concentric circles without touching either edge. The dragging task according to the specification (not shown), could involve selecting from pull down menu or moving an object between windows. Other tests may be devised to assess free-hand or ‘grasp and park’ actions.

Throughput in bits per second, a measure of input speed, is then defined for all tasks as I_{De} / t_m where t_m is the movement time.

3.2 Text production via gesture

In addition to the functional assessment of 2D interaction, a number of metrics for text entry throughput are suitable for assessing general PC input and Augmentative and Alternative Communication (AAC) applications such as Voice Output Communication Aids (VOCA) or eye-typing.

Metrics for text entry are usefully summarised by Hansen and Aoki (2012). The metrics are based on text production speed and errors or corrections made, as follows: Words per minute (WPM); Rate of backspace activation (RBA), Keystrokes per character (KSPC); Minimum string distance (MSD) – the number of substitutions required to correct a word; Overproduction rate (OR) – ratio of actual to minimum number of keystrokes. These metrics are suitable for different means of physical input other than gaze. The authors also consider two gaze specific metrics suitable for onscreen eye-typing: Read text events per character (RTE) – the ratio of the number of gazes to the onscreen text field and the number of characters actually typed; Attended but not selected rate (ANSR) which is the ratio of the number of keys gazed at but not typed e.g., gazed at less than the threshold dwell time) and the number of characters actually typed.

3.3 Comfort and training

ISO/TS 9241-411:2014 includes metrics for user comfort. There are two sets of rating scales, one for independent evaluation of a single device and the other for pairwise comparison.

The Independent Rating Scale for single devices is a 7-point scale comprising of the following indices of comfort and fatigue:

- Force required for actuation (Very uncomfortable → Very comfortable)
- Smoothness during operation (Very rough → Very smooth)
- Effort required for operation (Very high → Very Low)
- Accuracy (Very inaccurate → Very accurate)
- Operation speed (Unacceptable → Acceptable)
- General comfort (Very uncomfortable → Very comfortable)
- Overall operation of input device (Very difficult to use → Very easy to use)
- Finger/Wrist/Arm/Shoulder/Neck fatigue (Very high → None, each part of body rated separately)

The Dependent Rating Scale for comparing two devices A and B uses a 5-point scale (Most negative → Most Positive for the general indices and Extreme → None for the fatigue indices) for input device A, and -1 (Worse), 0 (Same) or -1 (Better) rating for device B.

In addition to the these rating scales, the Borg CR10 scale (Borg, 1982) is suggested for determining perceived exertion effort for arm, shoulder and neck. The standard also stresses the need for training of participants on unfamiliar devices and checking that learning effects have stabilised before testing. The training process should present a standard set of instructions whereby the user is asked not to correct errors during stabilisation and a statistical technique such as Duncan's Multiple Range Test (Duncan, 1955) is used to check that stabilisation has been achieved.

3.4 Caveats for real-world deployment

There are a number of issues to be considered for enabling good translation from the laboratory to the real world, usefully described by Hill *et al.* in the context of Brain Computer Interfaces for AAC

(Hill, Kovacs, & Shin, 2015). Four critical issues for assessment were identified: matching system features to individual requirements at multiple levels (language support, user Interface and hardware), aligning to a standard functional and disability assessment framework, focussing on language as the primary level of system assessment, and direct measuring of end-user benefit during and after intervention. Heikkilä and Ovaska (2012) list some particular caveats about transferring evaluation results from lab testing, summarised as follows:

- Lab tests with pre-set text do not require the thinking time that is involved in real-world composition so production throughputs are likely to be lower outside of the lab.
- Users may act differently in the lab when reading text if they are not also required to understand the content.
- A/B comparisons between different input devices may not be 'fair' if the user is much more familiar with the baseline system (such as mouse or keyboard input).
- Lab-based methods may use calibration methods e.g., chin rests that would be unacceptable to users outside of the lab so it will be important to test calibration in the real-world environment.

3.5 Case Studies 1: Camera Mouse

To illustrate the above functional evaluation techniques, the first case study for this chapter will now be introduced. Camera Mouse (Betke, 2002), which was developed some 15 years ago, is a PC application that uses video to track body features for controlling computer mouse motion and employs dwell time to generate mouse clicks. The interface was designed for persons with limited voluntary motion or dexterity and limited ability to vocalise (so unable to reliably use speech input as an alternative), but are able to control their head or move a finger. Due to low cost of high resolution webcams and free download of the software, Camera Mouse is a readily available camera-based system for gestural input.

To select a bodily feature, the user is helped to click a preferred point on a video of themselves shown on the screen and the software then extracts a small square template image around that point which is tracked in subsequent video frames. The position of the moving template becomes the cursor position. In the original paper, the camera was tested with eye, lips and thumb. The authors gave insights about the quality of the tracking (such as: benefits of image contrast within the template; effect of relative size of the feature in the video field; limits to speed of movement before tracking is lost, and lighting levels) and also discussed a number of set-up criteria, including choice of body feature for the tracking, dwell time and boundary radius for generating mouse clicks (defaults 0.5 seconds and 30 pixels). Horizontal and vertical gain can also be set separately.

Other researchers have developed the Camera Mouse concept further and have carried out more systematic user testing. Magee et al. (2015) recently reported a comparison of Camera Mouse (CM1000, with a dwell time of 1.0 seconds) and Camera Mouse plus ClickerAID (CM_CA) which supports selection by means of single muscle contraction chosen to suit the user (e.g., eyebrow, jaw, cheek, chin), and Touchpad input for baseline comparison with both CM systems. Initial trials with 29 persons (presumed to have no motor disability) were performed on a standard multiple directional tapping task, FittsTaskTwo. Mean movement time, throughput in bits per second, dependent variable error rate and 'target re-entry' rate were reported. It was seen that the touchpad outperformed both CM alternatives in speed and throughput but CM_CA was better than

CM1000. Target re-entry rate was similar for all devices but error rate was highest for CM_CA. The authors investigated the reason for errors and observed differences between individuals in that some CM_CA users were clicking before the mouse was at rest (which is not possible with dwell-based CM) and some Touchpad users had made errors due to dragging the cursor after touching whilst other users made zero errors.

The CM_CA system was then tested by a single individual (co-author with neuromuscular disease Friedreich's Ataxia) in his work office environment, with Camera Mouse tracking his nose and ClickerAID (via a headband sensor) controlled by raising his brow muscle. CM_CA was tested against Camera Mouse alone with two different dwell times CM1500 (1.5 seconds) and CM2000 (2.0 seconds) and using a Trackball input device (instead of the Touchpad from before) as a baseline comparator. Results showed that CM1500 provided best speed and throughput followed by CM_CA, and the trackball had the lowest error rate and re-entry rate followed by CM_CA. The user expressed a preference for ClickerAID for clicking, since it required less effort than the trackerball, which required lifting the hand several times between targets in the multi-directional test, but still allowing him to 'stay in control' versus CM alone since he was unable to keep the mouse pointer completely still.

It can be seen that the above summary description of a Camera Mouse comparative study is fairly representative of the ISO 9241-411 standard approach to physical input device evaluation with its use of a multi-directional test and reporting of throughput and error metrics. Such an approach enables an evaluator to form a more in-depth assessment of the pros and cons of a new device. Clearly there were some advantages to the combined CM_CA system for a motor-impaired user even if it was not optimal in any one test. So, whilst the evaluation did not report a systematic evaluation of effort or degree of control it is illustrative to see that the 'best' solution was not based on test performance alone, but included non-functional aspects that were important to the user, and so the innovation was therefore judged superior on a multi-criteria basis. Final points to take away from this case study are that, although the CM_CA system was new to the user, the experiment can still be considered to be an expert-user study due to their prior experience with similar systems, and also that the environment of use (workplace office) and seating position was familiar. The next case study will consider in more detail the process of evaluation from a user-centred perspective.

4. User-centred approach to evaluation and customisation

4.1 The KEE concept

The success of an assistive technology requires a user-centred approach (see Introduction to Section I, Chapter 3 and Chapter 13 of this volume). Donegan et al. (2012; 2009; 2006) as part of the COGAIN European programme on Communication by Gaze Interaction developed an action research methodology termed the 'KEE' concept - Knowledge-based, End user-focused and Evolutionary - that was aimed at introducing users with complex disabilities to gaze interaction technology. Although KEE was developed for eye-tracking, the reader is encouraged to generalise this useful approach to other input devices.

The authors are keen to point out that gaze interaction will be a new skill to learn for most users whether they have a disability or not, so engaging them in a trial of eye-tracking technology requires careful preparation and planning. The overall philosophy of KEE is to customise each trial with the particular user in mind, with the aim of producing a relaxed but focussed environment to try the technology out in, creating a positive experience overall. The objective is to maximise potential for success and to determine what changes need to be made to progress the user to an acceptable real-world outcome.

In KEE, ‘Knowledge-based’ refers to gaining an in-depth understanding of the user, ‘End-user focused’ is about designing a solution to meet an individual’s needs and interests and ‘Evolutionary’ indicates readiness to change the system in response to the user’s trying out of the technology. To realise the philosophy, KEE considers a trial with the technology in four parts: Pre-assessment process; Calibration process; Assessment Activities; and After the Assessment.

‘Pre-assessment’ involves fully understanding the individual’s background information: physical, communication and cognitive abilities. For eye-tracking, visual ability is of particular importance. Personal interests are also explored. Then, in the knowledge that the experience may be stressful and put pressure on the participant to do well, it is important for researchers to manage expectations so that any failure is ascribed to limitations of the technology or the experimental conditions, not the user. Other aspects of pre-assessment include adjusting the physical environment such as lighting and deciding if third parties may be present, since too many onlookers could be detrimental for some users.

‘Calibration’ is about using the information about abilities and preferences to customise the system as far as possible. Examples given for eye-tracking are: choice of one or two eye calibration; choice of feedback e.g., should the system speak out letters or symbols; customising targets so they are visible and comprehensible. Further details include: finding the best mounting position for the eye-tracker and determining the user’s most comfortable position with respect to it e.g., they may be more comfortable lying down; organisation of targets on the screen to fit the individual’s visual scanning ability, range and direction of eye-movement (which may be more or less impaired in different directions). The degree of customisation possible during calibration will of course depend on how flexible the technology platform and software was designed to be.

‘Assessment’ is divided into three sub-sections. Before starting, the user is reassured about the expectations of the trial. Introductory ‘warm-up’ activities are then used to present less cognitively demanding exercises to begin with to allow the individual to get used to the interface, and then make changes if need be. As with calibration, personalising targets and feedback with familiar and enjoyable themes is recommended at this stage. During warm-up it is possible to try out a range of selection techniques such as dwell time, blinks/winks or use of switches. Then the assessment itself can proceed.

‘After the Assessment’ is also termed the ‘implementation period’ where the potential of the system is realised in the real-world and need for further customisation is explored, including the potential for involvement of system developers/manufacturers to make this happen.

4.2 Case studies 2: Use of KEE to optimise gaze interaction with end-users

Donegan et al. describe a number of examples of the use of their KEE approach with end-users. In Donegan et al. (2006) it was reported that by using KEE to personalise the gaze interface with her needs and interests, one young end-user was able to progress from non-use to writing emails independently, by starting off with a pictorial grid and progressing over time to a text-entry system. For another end-user with nystagmus (involuntary eye-movement) and involuntary head movement, KEE was used to improve the calibration process and so adapt existing software to enable him to write on a 3x2 grid consisting of a hierarchical sets of words (people, places, alphabet, numeric & punctuation functions, extra functions). In Donegan et al. (2012) a third example of the use of KEE was presented for a user with nystagmus and blurred vision, using the Sensory Software Grid 2 software package. Musical feedback was first used to determine the user's optimal grid size for gaze interaction. Colour contrast of grid squares was initially chosen by trialling a range of foreground and background colours and positioning the writing cells according to preference. Colours, layout and grid content were adjusted over several iterations which resulted in a highly customised and personal solution allowing the user to write successfully. Donegan et al. (2009) gives further detail on the first two cases above and several other cases, and adds a more clinical approach to the evaluation methodology with the use of quality-of-life, depression and burden scales. It also presents the COGAIN eye-tracking questionnaire used to measure four aspects of satisfaction and another more general questionnaire to capture frequency of use, ease of learning, learning after 7 days and overall satisfaction.

The idea of KEE to maximise the results of user-centred evaluation speaks for itself. The authors conclude that there is no such thing as 'the best gaze control system'. Instead, interfaces should be customised and evolve to fit with users' needs and preferences.

4.3 Gaze interaction for environmental control and mobility

The previous section and case study has focussed on computer access. Gaze interaction for environmental control and mobility is an area of research which is ripe for further development. In addition to typical usability assessment, evaluation of technologies for control of domestic products and navigation must consider safety i.e., ensure that the system behaves in a safe manner and enables the user or carer to respond to safety critical events e.g., 'A carer or assistant must be able to stop the wheelchair in an emergency' (Bates et al., 2012). Technological solutions include adding proximity detection and alarms as feedback. Evaluation of response time is needed to ensure the user remains in control.

5. Gesture-based systems for motor rehabilitation

5.1 Stroke rehabilitation systems

In addition to its use in AT and AAC, gestural interaction technology is finding use in post-stroke and other muscular skeletal rehabilitation. This can be considered to be an assistive technology in terms of therapy being taken out of the clinic and into people's everyday environment. Research in this field is very active and is continually developing to make use of newer devices. Much of the research in developing technological solutions for rehabilitation is focussed on stroke survivors with the aim of better fulfilling national guidelines on intensity and frequency of therapy.

If rehabilitation is remote and unsupervised by a healthcare professional (one modality of telerehabilitation), there is a challenge in patient adherence to the therapeutic regimen and ensuring correct performance of task-specific exercises without compensatory actions which could limit motor recovery. Gamification is one strategy that is of particular interest with the aim of motivating patients to perform the recommended exercises on low-cost platforms (Putrino, 2014). A systematic review of 24 virtual reality and video game therapy studies by Lohse et al. (2014) showed superiority of such games for post-stroke adults compared to conventional care. Saposnik et al. (2016) recently showed in a randomised controlled trial that using commercially available games on a Nintendo Wii console was as safe and similarly efficacious as other leisure activities such as playing cards. Wittman et al. (2016) showed that self-directed home therapy was safe and could provide a high dose of rehabilitative therapy.

Standen et al. (2015) explain that whilst the UK's National Clinical Guidelines for Stroke recommend 45 minutes of therapy 5 days a week, patients in clinic are receiving between half and a quarter of this, and also that time spent on upper limb activities during rehabilitation sessions is less than 8 minutes. Furthermore, half of patients that are discharged having some symptoms or disability are not referred for additional rehabilitation, and of those that are sent home adherence is 50-55%. To address this, the authors designed home-based and gamified rehabilitation systems based on various technologies including a glove tracked by a Nintendo Wii remote and the Microsoft Kinect depth sensing camera system that is conventionally used with the Xbox games console. Use of mass market games console platforms provides low-barrier access to gestural interaction and good graphics, and places rehabilitation technology in people's living rooms.

Other researchers have investigated the use of alternative camera-based systems such as Leap Motion (Smeragliuolo et al., 2016) and there are numerous examples of the use of commercially available bespoke input devices using, for example, gloves and vests to capture hand, shoulder and trunk information more directly (Adamovich et al., 2005; Delbressine et al., 2012; Steffen, Schafer, & Amirabdollahian, 2013).

5.2 Usability of computer and wearable technology in stroke rehabilitation

Mountain et al. (2010) investigated usability of home-based telerehabilitation and testing, and highlighted issues concerned with the sensors and methods of attachment, interpretation of on-screen presentation and appropriateness and acceptability of equipment in domestic settings, and also found the need for users' education and support throughout the testing period. Parker et al. (2014) examined extrinsic feedback requirement for telerehabilitation and uncovered key elements such as accuracy, measurability, rewarding feedback, adaptability, knowledge of results and a number of personal and environmental contexts including previous experience of service delivery, personal goals, trust in the technology and social circumstances.

Bergmann and McGregor (2011) reviewed user preferences for body-worn sensor systems, which included applications in post-stroke rehabilitation and a number of other clinical domains, looking at both patient and clinician preferences. For stroke survivors, findings from the literature were that systems needed to: minimise incorrect use; have a simple interface; be compact (light and small), be simple to operate and maintain; be usable independently; be available alongside the work of health professionals; provide positive feedback to patients; and motivate users. For clinicians the preferences were that sensors should be integrated in clothing; have a real-time function; assist the patient in their training; have a library of reference movements; be able to monitor progress; and have training and education embedded to explain how the system works.

5.3 Case studies 3: Evaluation of stroke rehabilitation

Since they are implementing therapies within clinical practice, it is unsurprising that evaluation of technological solutions is couched more in terms of clinical outcomes compared to AT and AAC. For post-stroke motor rehabilitation there are a large number of scales (Baker, Cano, & Playford, 2011) which cover function, independence in daily living and quality of life.

In the virtual reality trial introduced above (Saposnik et al., 2016), the primary outcome in the trial before and after the 2 week intervention period was upper extremity motor performance measured by total time to complete an abbreviated form of the Wolf Motor Function Test (WMFT) (Wolf et al., 2001; Wolf, Lecraw, Barton, & Jann, 1989) where patients were asked to perform a series of tasks as quickly as possible. Six tasks were chosen from the WMFT (hand to table, hand to box, reach and retrieve, lift can, lift pencil, and fold towel) and the authors added two further tasks: grip strength and flip-a-card. A number of other tests were used for measuring secondary outcomes of manual dexterity, quality of life, functional independence, independence in activities of daily living, disability severity and grip strength. All tests were repeated at 4 weeks post-intervention. In addition, the kinematics of limb movement were measured before and after the intervention to assess motor learning and assess compensatory motion. Perceived exertion and fatigue were measured after each exercise using the Borg Scale and adverse events were recorded.

In their trial with the glove and Wii based system, Standen et al. (2015) also used a set of clinical measures: WMFT (as above), Nine-hole peg test (Kellor, Frost, Silberberg, Iversen, & Cummings, 1971), Motor Activity Log (Taub et al., 1993) and the Nottingham Extended Activities of Daily Living Scale (Nouri & Lincoln, 1987). In addition, the software logged frequency of use to see how close therapy duration and frequency were compared to recommended. For each participant the study recorded the percentage of recommended use, daily duration of use and the number of sessions (either no use or 1, 2, 3 or 4+ sessions per day). Interviews were used to explore barriers and facilitators to using the intervention as recommended. Barriers to use were found to include technical problems experienced, confidence with technology, dependence on others to use the technology, health problems, competing commitments and the desire to get back to pre-stroke activities. Facilitators included being able to carry out rehabilitation exercises at any time, motivational aspects of the games, using the system to alleviate boredom, belief in the health benefit and family support.

Psychometric instruments used by Delbressine et al. (2012) to evaluate table-top video games employing an wearable (accelerometer-based) input device included Intrinsic Motivation Inventory (IMI) (McAuley, Duncan, & Tammen, 1989) and a Credibility/Expectancy questionnaire (Devilly & Borkovec, 2000).

From these three examples and the above findings in the literature about usability, feedback requirements and personal/social contexts it is seen that evaluation is best conducted using the biopsychosocial principle. Choice of scales will depend on clinical practice and preferences of healthcare professionals in the geographical area where the technology is being evaluated. The capturing of users' individual needs, motivations, domestic arrangements and social relationships all contribute to a successful evaluation outcome.

6. Sign language recognition

Sign-language recognition (SLR) is a technology related to gestural interaction that is still in the research or early prototype domain, but it will now be briefly introduced. Cooper, Holt, and Bowden (2011) provide a comprehensive review of state-of-the-art from a few years ago.

SLR is the interpretation of bodily gestures, expressions or poses for the purpose of communication, as used daily by many deaf or hearing impaired persons. The goal of automatic recognition is real-time translation of sign language into speech or text for understanding by non-signers or as a means of human-computer interaction. Conversely, although not considered further here, systems that translate text or speech into sign or could support interpreting between different national sign languages are also in this area of interest.

Evaluation of SLR can be considered at different levels. At the lowest level, recognition of hand poses, body posture, lip shape and facial expressions are all very challenging pattern recognition problems which are being approached with a variety of different artificial intelligence methods. As Cooper et al. explain, SLR has some of the characteristics that also make speech recognition a difficult problem, such as co-articulation. Added to this, however, is dealing with the non-sequential aspects of sign production and obscuration between hands or from clothing. The construct of sign languages also provides many challenges. Non-manual features (facial expression), sign placement, body shift and positional signs (relationships of hand poses to other parts of the body, other people and objects in the environment) and adverbs that involve the relative speed of gesture are just some of the constructs that a recogniser must be able to deal with. Also, inter-signer differences are large. At the production level, similar to gestures, throughput of sign production and recognition can be computed and errors measured by observation or with respect to standard corpuses of different sign languages.

7. Further reading and newer technologies

For reasons of space and maintaining a holistic approach, with the exception of the case studies, this chapter has not gone into any great detail of specific technologies. Some suggestions for further reading are therefore offered, and some interesting newer technologies and applications are highlighted in order to complete the picture.

Applications of eye-tracking, including computer access and AAC, mobility and environmental control, are considered in more detail in the excellent volume from the COGAIN programme *Gaze interaction and applications of eye tracking : advances in assistive technologies* (Majaranta et al., 2012), content from which has been drawn on earlier in this chapter.

For the specifics of touch interaction, although it does not consider accessibility, the edition *Brave NUI world* (Wigdor & Wixon, 2011) is a good introduction to the design challenges for touch and considers the Midas Touch problem in some detail, which helped inform the earlier section on this. *Designing Gestural Interfaces* (Saffer, 2009) is another edition that is mainly about touch interaction. Since touchscreens are now ubiquitous and cheap, touch interaction is an area where greater focus on usability is to be expected. One specific assistive technology worthy of note with respect to touchpad interfaces is Gest-Rest (Carrington et al., 2016), a prototype set of 'chairable' (c.f. wearable) technologies which integrated switches, touchpad and force/pressure sensing into wheelchair arm-rests. The authors evaluated and compared four variants of Gest-Rest using a defined set of gestures to test tapping, holding, directional and pressure-based input with both manual and motorised wheelchair users, and also collected opinion from physiotherapists and occupational therapists.

Wearables, referred to earlier with respect to usability of telerehabilitation technology, are receiving active attention by researchers. Fitness trackers and smartwatches containing motion-tracking technology are becoming ubiquitous with a low price barrier. Some products have open application programming interfaces which is encouraging researchers to experiment with their use as gestural input devices e.g., WristRotate (Kerber, Schardt, & Löchtefeld, 2015). Other ideas in the prototyping phase include using smart textiles as input devices e.g., GestureSleeve (Schneegass & Voit, 2016) which uses stroking or tapping gestures on a sleeve to control a smartwatch and the embedded radio-frequency microstrip e-textile of Hughes, Profita, Radzihovsky, and Correll (2017) that can detect finger positions and basic gestures. With application in wearables, mobile devices and internet of things, Google's Advanced Technology and Projects (ATAP) division is developing Soli, a gestural interface based on miniaturised radar that is aimed at processing near-distance finger interactions with virtual buttons, dials and sliders (Google, 2016), whilst Chirp Microsystems is a recent university spinout focussing on interaction via on-chip ultrasound (Przybyla, 2015). One other recent application of ultrasound imaging in hand pose detection is EchoFlex (McIntosh, Marzo, Fraser, & Phillips, 2017). Analysis of 'bio-acoustic' or 'vibrotactile' signals from higher rate sampling of accelerometer signals is also under investigation with application in fine gesture classification (Khan, Hammerla, Mellor, & Plotz, 2016; Laput, Xiao, & Harrison, 2016; Shao, Hayward, & Visell, 2016). A clinical application of wearables is falls detection for elderly people using motion sensors embedded into pendants, watches, clothing or shoes. User evaluation research in this area highlights the importance of both intrinsic and extrinsic factors (Hawley-Hague, Boulton, Hall, Pfeiffer, & Todd, 2014). It can be seen that much of the reporting on developments in the wearables field is to be found in technology-orientated sources. Some adaptation of existing methodologies and standards will no doubt be needed for their functional evaluation and testing with users with impairments.

Summary of the chapter

A holistic approach to assessment of gestural input and tracking technology for AT, AAC and rehabilitation applications has been presented. Case studies have been taken from the literature to cover typical evaluation approaches. These have been selected to introduce lab-based functional assessment and ISO standards for physical input devices (including consideration of user comfort/effort), user-centred approaches for assessing and evolving technology solutions in the real world, and clinical evaluations that include outcomes scales in current use for assessing a patient's function and daily living abilities, and highlighting the need to address psychosocial factors.

Choice of method will depend on stage of design of an input device and its application as an AT, in AAC or for rehabilitation. Functional evaluation is most appropriate during technology development and it is seen that standard tests are available for this purpose. Although these tests are for physical input devices in general and are not specific to users with physical impairment, the Camera Mouse case study shows that they are useful in assessing independent and comparative performance of applications of assistive technologies. Comparison of a single technology against a standard database (such as a sign language corpus) is another approach. It was seen that when users involved with testing are faced with a new interaction technology it is necessary to provide opportunity for training and to ensure stabilisation of learning as part of the assessment process, in order to ensure optimal results and perform fair comparisons.

A user-centred method such as KEE is important for summative evaluation of assistive solutions, to explore user preferences with existing technologies and to guide their customisation. Although user-centred design philosophy may suggest it is never too soon to bring end-users into the design process, it is seen that there are risks in presenting technologies that are sub-optimal. Related to this, expectations need to be carefully managed. Making tasks less challenging to begin with and tuning them to a user's interests are some of the suggested ways to ease the introduction of novel interaction technologies.

Clinical assessment has its own rules, requiring alignment to existing practice and an outcomes based research approach. It is seen that healthcare professionals have needs and opinions in addition to patients and so they are ideally considered as a part of assessment in the clinical domain. This is equally so when AT use is being supported by a care-giver.

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