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RESEARCH PAPER

Crucial design issues for special access technology; a Delphi study

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Abstract

Purpose. To develop and demonstrate a method to involve professional users of assistive technology (AT) in the development process of customisable products. Employing the ideas of user participation and mass customisation, this research addresses the need for reduced product costs and optimised product flexibility.

Method. An adaptable six-question Delphi study was developed to establish consensus among AT professionals on design issues relating to a specified AT domain requiring innovation. The study is demonstrated for the special access technology (SAT) domain. A modified morphological matrix structures the application of the study results to the product design process.

Results. 14 Professionals from the Republic of Ireland and the UK participated. Consensus was reached on prevalent parts of SAT that malfunction, primary reasons for SAT malfunction, characteristics of clients associated with SAT selection, client needs regarding SAT use and training, desirable traits of SAT, and clinicians' frustrations with SAT.

Conclusion. The study revealed a range of problems related to SAT, highlighting the complexities of successful SAT adoption. The questions led to differentiated insights and enabled design solution conceptualisation from various perspectives. The approach was found to help facilitate efficient generation and application of professional users' knowledge during the design process of customisable AT.

Implications for Rehabilitation

- High product costs and device abandonment negatively affect many people who use assistive technology (AT). Poor device design is a root cause of these two problems. To address this issue, a method for the practical concept generation of customisable AT is proposed and demonstrated. The method aims to support the development of new, low-cost products which satisfy a broad range of consumers' needs.

- The literature requests suitable methods to facilitate the involvement of different types of AT users in the product design process. This paper presents a method to first establish consensus on important design issues for a specified AT domain, and subsequently to apply these issues to the product design process.

- This paper describes the method's application for a customisable special access technology (SAT) device. Crucial design issues for SAT devices are presented to assist future SAT development work in research and industry.

- This research supports and provides validation for a number of past studies about desirable criteria for AT. These studies declared that further research was required to confirm their results.

Introduction

The anatomical constitution of a person does not define their ability. Rather, it is the combined effect of how others perceive and treat them; how easily they can access educational, vocational and social activities; and how well their material and technological environments fit their needs. A person's ability is better defined by their capacity to participate in the activities of their society. This concept reflects the social model of disability [1] and asserts that the responsibility for creating equality rests with society, rather than the individual. Undoubtedly, rehabilitation and other medical interventions help to equalise the abilities of people, but positive changes in societal attitudes, human rights legislation, and universally accessible buildings and technology also have great equalising effects.

Until inclusive access becomes ubiquitous, appropriate assistive technology (AT) has the power to serve as an integrator [2, 3], enabling greater independence [4] and effectively closing the gap between individuals with and without disabilities. In harmony with the social model, Hersh and Johnson [5] describe AT as a mechanism to help people overcome barriers to independence, facilitate full participation in society, and accomplish activities safely and easily. Appropriate AT not only improves the user's quality of life [6, 7]; it also has the potential to reduce personal and government expenditure by empowering individuals with greater autonomy and independence, and consequently facilitating a more inclusive workforce [6].

Regrettably, there are problems with AT. First, consumers must deal with its relatively high cost [8-10]. Prices are higher than similar mainstream products in part because AT tends to target niche markets [11] and so suffers from poor economy of scale. The small market segments relate to the wide array of unique end-user needs that different products attempt to satisfy. These needs may be influenced by a range of physical, sensorial, speech-language and cognitive variables such as dexterity, vision, articulation or intellect. Since the literature shows that between 70-90% of a product's lifecycle costs are established once a product design specification is finalised [12, 13], it follows that to reduce the costs of AT, it would be useful to look at ways of optimising its design process.

Technology abandonment is another problem with studies showing that between 30-80% of all AT is discarded by the user [14, 15]. Inappropriate product design is a major basis for this, leading to AT that is difficult to use, fails during use and has poor aesthetics resulting in the user feeling stigmatised [14, 16, 17]. Lack of consideration of end-user opinion during device procurement and changes in their needs due to rehabilitation or preference changes can also cause abandonment [14, 18]. Negative outcomes manifest as wasted financial resources [19] and frustration.

This research aims to bring an improved design method to the state of the art in an attempt to reduce the cost and rate of abandonment of AT. At present, a hypothesis for a cure-all solution is not clearly determinable in the literature, perhaps partly because so many disciplinary variables affect cost and abandonment rates. These include the monetary resources available for the purchase of AT; the severity of disability experienced by an individual; the type of technology that is needed and obtainable; the changes in user needs; the availability of training; and the effects of family and other support systems. This research aims to address the problems by synthesising contemporary theories from two disciplines in a synergic framework for AT design. These are mass customisation from design engineering and the idea of participation from social science.

Mass customisation is the customisation and personalisation of products and services for individual customers at mass production prices [20]. Theoretically, customisable AT has the potential to reduce cost and abandonment in two ways. Firstly, adaptable devices that could facilitate a greater number of individuals' functional variables would have a larger target market, resulting in an opportunity for improved economies of scale during manufacture. Funding constraints could, therefore, be reduced so more individuals could access the technology. The second hypothesis relates to the multiple product purchases and redundant AT that can result from changing user needs [14, 18]. Customisable devices have the potential to adapt with these changes and reduce the associated frustration. Furthermore, customisation of device aesthetics could add the opportunity for personalisation, self-expression and psychological ownership [21]. Although adaptability has been cited as a desirable trait for assistive products [22, 23], specific methods for designing them are not available. This research attempts to address this.

The literature provides justification for user participation during the design process, most evidently in the area of human computer interaction. Recently, the idea of involving users in the product design process of AT has been highlighted by a number of studies [24-29]. Bridgelal Ram et al. [30] explained that although there is substantial evidence in the literature describing the benefits of user involvement, research concerning the process of involving users during AT development remains weak and poorly defined. Allsop et al. [31] demanded guidelines on existing methods to involve disabled individuals in the design of healthcare technologies and the development of effective ways for users to be involved in the design of AT. To address these demands this research aims to develop, demonstrate and evaluate a new framework for customisable AT design, which involves users who work with AT in a professional capacity, such as therapists and training providers, and end-users with disabilities. This research builds on a number of frameworks which have been developed over the last 15 years to guide the design of AT. Shah and Robinson [32] formulated a theoretical framework for the development of medical and assistive technologies. They concluded that two streams of user involvement are necessary to facilitate the participation of both end-users and professional users. Their framework advocates the use of a variety of tools, including interviews, surveys, focus groups, usability tests and observation. The FORTUNE project [33] is only concerned with the participation of end-users, but also promotes the use of similar tools. The USERfit methodology [34] similarly aims to help collate design information and proposes the use of data capture tools like brainstorming, task analysis and empathic design. The author declares that it is a meta–toolkit rather than a detailed design tool. Though useful as a reference for AT design, Hersh [35] noted that it is time-consuming to use. These three approaches are all useful references for AT design practice, but their purpose is not to provide specific instructions to execute an AT design project. Though advocates of a variety of user-centred design tools, they leave the selection and implementation specifications up to the reader.

This paper describes the first step towards addressing this gap. Sharing the user-centred philosophy of the frameworks mentioned above, this research focuses on providing a prepared structure for gathering and translating participant input into design solution concepts. In response to the identified criteria for good practice in disability and design research, the intention is to develop a process that will empower all participants, while generating explicit and actionable design specifications for customisable AT.

In order to demonstrate the process, the practical development of a new special access technology (SAT) device scaffolds the research process. SAT was selected because it has been identified as requiring more flexible and universal solutions [40]. The relevance of SAT is further supported by evidence highlighting the benefits of electronic assistive technology (EAT) [37-40]. Examples of EAT are power wheelchairs, communication aids, environmental controls and personal computers. In order to control EAT, peripheral devices are often required, including a computer input device. Mice and keyboards are typically used but in certain cases, adapted and alternative computer input devices, also known as SAT, are utilised. Examples are switches, joysticks and screen-scanning software.

The SAT domain not only presents the problems of cost and abandonment. Repetitive movements necessitated by the use of input devices has been linked to the growing issue of repetitive strain injury (RSI) [41]. Studies show that RSI costs US employers more than $6.5 billion annually [42]. This highlights the benefits which may be offered by a universal design, desirable as both a mainstream and assistive product. In theory, if a user could adapt and change their mode of computer control, they could avoid making the same repeat movements and so reduce the associated strain. This reflects the idea of adaptive mass customisation and emphasises its suitability to AT design. The adaptive approach leads to products that users can alter themselves so depending on the activity, devices can perform in different ways [43]. Currently, SAT devices are often adapted by users in an improvised fashion. For example, a tennis or stress ball may be attached to the lever of a joystick for more comfortable and satisfactory use. The idea of adaptive mass customisation is supported by Davies et al. [44], who found that EAT users often employ a combination of SAT devices depending on the computer program they are accessing. This paper describes the first phase of a new design method which facilitates the involvement of professionals working in the clinical AT arena. A later phase, beyond the scope of this paper, will facilitate the participation of AT users with disabilities.

Method

The method described in this paper has two parts. First, a Delphi study establishes consensus among professional users on a set of crucial design issues for the domain under investigation, in this case, SAT. Then, these issues are applied to the product design process using an adapted morphological matrix.

A Delphi study is an iterative process which aims to collate judgments from a group of experts in order to develop consensus on an issue [45]. By its nature, product design involves compromise. Cost is often a powerful influence on feature selection and design specification, but usability decisions may also involve compromise. Generating consensus among a group is useful during product design because more information becomes available, more alternatives are likely to be generated, more acceptance of the final decision is likely and better decisions generally emerge [46, 47]. To facilitate consensus generation, a Delphi study involves a series of questionnaires and management of participant feedback. Initially, open-ended questions are posed and participants list their responses. The researcher then collates unique results and returns them to the participants in a second questionnaire where they rate the importance of the responses. This data is then analysed to formulate consensus on a ranked list of results for each question.

The Delphi study was selected for three reasons. First, it fits with the participatory ethos of the research as participants essentially design their own questionnaire and work together to reach consensus. Second, Delphi studies are ideal when participants are time-constrained and geographically disparate because there is no requirement for face-to-face meetings. Finally, it is an anonymous process as participants do not meet and all responses are treated equally. This is beneficial because the aim of this study is to arrive at a consensus among different types of professional users. Other methods that facilitate dialogue between participants are workshops and focus groups. Theoretically, these methods encourage open communication in a setting where participants are valued as equals, but when different parties are involved, status and pressure can affect responses. Individuals might not want to speak out against a system, a purchased product, a decision that someone else has made, or a product that they have previously prescribed. The anonymous nature of the Delphi study supports the ideas of equality and provides participants with a safe outlet for frank responses. To ensure this paper provides adequate instruction for the method's implementation, Sinha et al.'s [48] checklist of inclusion material for Delphi study reports has been used.

The second part of the method involves a matrix which is based on General Morphological Analysis [49]. This approach is often used during the concept generation phase of new product development to investigate and organise alternative solutions for defined product functions [50]. Crucially, a morphological matrix is not a replacement for creative design thinking. Rather, it frames the designer's cognitive process and structures the development of design alternatives. Typically, the format is a grid of columns and rows. Product functions are listed in a column on the far left and each row is populated with design solutions depicted by sketches or text. Once the matrix is established, the designer combines individual solutions to develop larger conceptual designs.

Participants

The aim of this research is to construct a method to involve professional AT users in the design process of customisable AT. Occupational therapists, physiotherapists, speech and language therapists, rehabilitation engineers and AT trainers work in different capacities to select, prescribe, modify, assess and offer training on AT. The expertise and experiences of every professional varies, but by using the Delphi study to establish consensus among the group, the intention is that a synergic set of outcomes are produced.

The literature refers to a group of Delphi study participants as a panel of experts. The quality of the results depends on their level of expertise, the research design and the process by which consensus is identified [51-53]. Pragmatism underpins this research so experts were defined by their practical experience of working in the field. Inclusion criteria stipulated that they work, or have worked, with adults using SAT; are involved in the selection, prescription, modification or training of AT as part of their job description; and agree to participate in the research voluntarily. The literature proposes that a minimum of 13 participants is adequate for validity in a Delphi study but that reliability is not significantly affected with more than 30 [45]. Sampling aimed to invite at least 45 people to allow for attrition. A non-random, purposive sampling technique was employed. Professionals were recruited from two AT service-providing organisations, one in the Republic of Ireland (ROI) and the other in the UK, specifically Northern Ireland (NI). Data collection was carried out between September and December 2011.

Research Instrument

The method involves a Delphi study to generate input from professional users, and an adapted morphological matrix to structure the interpretation and translation of that input into product solution concepts. Appendix 1 shows an outline of the instrument structure.

<u>The Delphi study</u>

The first questionnaire initially poses demographic questions to verify inclusion criteria and facilitate sample description. Participants are then asked to list responses to six open-ended questions developed with respect to the Human Activity Assistive Technology model [54], the Comprehensive Assistive Technology model [5] and the Matching Person and Technology [55] model. Accordingly, the questions were grouped into human, activity and AT sections and prefaced with stimulus statements.

The first question asks participants to relate their experiences of device failure and malfunction. These experiences provide a list of specific, product-related issues that require attention. The second question asks about reasons for the failure and malfunction of a device. This helps the researcher to understand the context of the failure points listed in the first question and generate appropriate design solutions. The third question asks about the characteristic variables of an individual with disabilities that are associated with the use of the specified type of AT, in this case, SAT. This question highlights the elements of the product that need to be customisable. The fourth question aims to generate information to enrich the product package and associated services by asking participants about client requests regarding AT use and training. The fifth question enquires into participants' perceptions of their clients' AT preferences. This is asked to supply general, overarching criteria for the product design specification. The sixth question asks participants to identify any frustrations they may have had with devices. The intention here is to inform the researcher about real-life use contexts and associated issues so they can develop solutions. This question recognises that only individuals who are habitually working in a discipline can identify certain deficiencies and problems in products they use [24].

The second questionnaire is produced from the responses of the first. The six questions are presented with the responses and individual 5-point Likert scales. Participants rank the options on the scale where one indicates very unimportant and five signifies very important. In this way, panellists communicate their agreement with the anonymous group data and a consensus is formulated. As there is potential for a large list of generated variables, a series of only two questionnaires constitute this study to retain panellist involvement and reduce the redundancy a third might produce. Two questionnaires were used in a previous AT related Delphi study [4].

<u>The morphological matrix</u>

After analyses, the final results can be used to frame problems and aid conceptualisation of product solutions. Concept generation is a critical element of the design process as it dictates the majority of the cost and level of innovation of the product [50]. This paper presents an adapted morphological matrix as a way to drive concept generation with information provided by professional AT users. The matrix is shown in Appendices 1 and 3. It differs from typical morphological matrices in that instead of organising ways to carry out a product function, it arranges alternative solutions relating to the Delphi study results. The first column contains the design issues from the Delphi study, the second defines components related to the issues and the third explains the functions which the components fulfil or the functions associated with the issues. The last column contains alternative solutions proposed by the designer for each issue. Populating the matrix with useful content requires a designer with background knowledge of contemporary technologies available for exploitation. To help generate design solutions, each issue can be considered in respect to the following questions:

1. What mechanical changes could be made to resolve the issue?
2. What design features related to the issue do other products have?
3. What materials or technologies could be employed to resolve the issue?
4. By focusing on the product as a holistic system, can a novel or radical solution be identified?

It is beyond the scope of this paper to define the decision making process involved in selecting the optimum solutions. The research is underpinned by the principles of participation so important decisions concerning concept selection will involve users with disabilities. This advanced phase of the design research is currently underway.

Procedure and Ethics

Ethical approval was granted by committees in Dublin Institute of Technology and the AT service provider in the Republic of Ireland (ROI). The service provider in Northern Ireland granted approval based on these authorisations. Information packs, consent forms and the first Delphi questionnaires were sent to the e-mail addresses of professionals nominated by the gatekeepers. Those who agreed to take part returned the consent form and questionnaire. These participants were also asked to nominate and provide contact details for three other people within their organisation who shared their profession to consider taking part. This snowball sampling technique [56] embodies the participatory philosophy of the research as initial participants effectively partake in the sampling process. The new individuals were then sent the same packages. After receiving consent forms and completed questionnaires, data from the first questionnaire were analysed and the second was created and sent to the group. Participants could fill these out electronically or request a hard copy. They were informed of how long each questionnaire would take to fill out and asked to respond within two weeks. After this, reminders were sent to relevant participants. Responses were anonymous and equally valued. To track responses, a code was assigned to each participant and inserted as a header on their questionnaires. Their name was deleted from the code list when their second questionnaire was received.

Data analysis

Responses generated from the six questions in the initial questionnaire were entered onto six Microsoft Excel spreadsheets. Duplicate responses were deleted and any issues which were similar but not identical were combined into single issues. The second questionnaire presented these refined issues beside Likert scales and responses were then entered onto new spreadsheets. Analysis consisted of calculating the median (M) and interquartile range (IQR) for each issue. Issues with missing data were included and their respective numbers of responses were taken into account. M values indicated the level of importance at which half of the responses lay above and half lay below and IQR values supplied information about the variability of responses. A small IQR indicated high consensus and a large IQR signified low consensus. Issues with a high level of importance and a high level of consensus were deemed most essential.

Issues was then divided into four groups according to essentiality. Primary issues had an M value of at least 4.5 and an IQR of equal to or less than 1. In other words, a minimum of 50% of the panellists rated these issues as very important and at least 75% rated them as important or very important. Secondary issues had a first quartile (Q1) of at least 3.5, so at least 75% of the panellists rated them as important or very important. Tertiary issues were those with an M value between 4 and 4.5 and a Q1 value of at least 3, so 50% of the panellists rated these as important or very important and at least 75% felt neutral about the issue or believed it to be important or very important. Other issues were any that fell outside of these criteria. As a Delphi study strives for consensus, responses from participants with different professions and levels of experience were collated and analysed together. Consequently, although descriptive demographic information about the sample was collected, no cross tabulation analyses were carried out. The full data-set including the M and IQR values for each issue is available on request from the author.

Results

Response Rates and Demographic Data

Gatekeepers from two organisations nominated 18 individuals from various professions. Snowball sampling [56] brought a further 11 individuals. The recruitment rate was 48.3% (n=14) and the retention rate for the second questionnaire was 100%. Of the 14 participants, more than 70% had 10-15 years experience. Occupational therapists had the largest number of representatives (n=6) and made up 43% of the sample. Speech and language therapists and AT trainers each had two representatives. The sample also included one physiotherapist, one clinical engineering technician, one clinical engineer and one electronics technician. Table 1 shows the gender, profession, location and experience of the participants.

	%	n
Gender		
Female	71	10
Male	29	4
Profession		
Occupational Therapist	43	6
Speech & Language Therapist	14	2
Assistive Technology Trainer	14	2
Physiotherapist	7	1
Clinical Engineering Technician	7	1
Clinical Engineer	7	1
Electronic Technician	7	1
Location		
Republic of Ireland	64	9
Northern Ireland, UK	36	5
Years of Experience		
1 to 5	14.3	2
5 to 10	7.1	1
10 to 15	71.4	10
15 to 20	0.0	0
>20	7.1	1
Working with individuals using SAT		
Yes	100	14
No	0	0

Table 1 Demographic Profile of Participants

Delphi study Results

The first questionnaire generated 357 issues, of which 43% (n=154) were unique and included in the second questionnaire. Similar issues were combined; for example, participants stated that cables wear, tear, break, twist and fray in response to the first question so these were merged into a single issue. 116 Criteria constitute the final list of results, representing 32.5% of the total initial responses. Certain individual issues (n=4) from the omitted, less important tertiary and other groups were reintroduced to the final results. These were selected due to the possible bearing they could have on the design of a new product, or if they had been major results in relevant past studies in the literature. Appendix 2 contains the final set of results. These are ranked according to their essentiality in order to aid the formulation of a design trade-off strategy, if required.

Cables were cited as the most prevalent part of SAT that malfunctions. Other important mechanical issues were loose mounts, broken ports, unresponsive touch screens and worn connections between the cable and SAT. Keys and buttons were found to lift away from devices. Software issues related to calibration problems and driver conflicts. Internal issues were cited as switch contact and sensor failure. Participants agreed that lightweight switches break because they are prone to accidental activation. Dirt build-up was also said to negatively affect SAT use and small parts were cited as being easy to lose.

The top three reasons for SAT device malfunction or failure related to rough use. Devices fall or are banged, they are inappropriately used and cables tend to get caught or are roughly pulled from ports. Maintenance was another important issue, with participants citing battery conditioning, poor care during transport, and dirt, spills and dust contamination. Weak joints and poorly routed cables were mechanical issues. Software updates were found to cause problems with previously installed SAT drivers. Insufficient battery charge was another issue. The physical movement of a user was also said to be problematic because it causes mounting devices to loosen.

25 Issues relate to the characteristics of an end-user associated with selecting SAT. Physiological functions were range of motion, muscle tone, tremor, fine motor control, and ability to repeat movements without strain. Grasp, speed, strength, and wrist and finger functions like dexterity, sensory perception and proprioception were also highly rated. Vision, motivation, level of interest, stamina, cognitive ability, posture, the presence of pain and whether the user's condition was improving or degenerating all featured prominently.

Other issues related to the type of activity that the SAT facilitated, the user's environment, their level of independence, their social network and access to funding and technical support.

Issues associated with general SAT use and training were device positioning and mounting, accessing the SAT for trialling, and instilling the motivation to practice, explore and use the technology. SAT instructions in various media, information about SAT modifications, technical support data, product reviews, basic IT training, device demonstrations, and lists of frequently asked questions were all found to be important. Peer support was also cited, with participants agreeing that it is helpful to introduce new users to individuals who have experience of the SAT device in question. Participants also wanted recommendations for school staff and boards about the use of SAT in educational settings.

Participants agreed that the most desirable traits of SAT are that the device matches the user's goals; that it is comfortable and does not impede their movement; and that it is adaptable to the user's needs. Reliability, battery life, and easy set-up and disassembly were also important. Device aesthetics were highly rated and the group agreed that designs should be based on mainstream devices. Appropriate sensitivity, weight, size and tactile characteristics were other desirable traits. Participants stated that SAT should be flexible, multi-functional, robust, durable, portable, quick to turn on and install and easy to position and maintain. It also emerged that it is preferable when devices operate wirelessly and that SAT should be compatible with various operating systems and have clear menus on screen.

The most significant frustration which professional users associated with SAT was monetary cost. Device positioning in a multi-care environment was another major issue. This frustration relates to devices that must be used by a number of individuals with different needs – like in a school or training centre. As a consequence of this, therapists must regularly adjust the mounting device, but these adjustments can be difficult to replicate. The cost and time spent on SAT repair and training along with limited access to technical support were other cited issues. Participants were frustrated by SAT that is not adaptable for different users or a user's changing needs. They also disliked SAT devices which are not 'plug and play', and cited funding inequalities and lack of follow through by families and schools as problems.

The morphological matrix in Appendix 3 is an extract of the matrix which was completed for this research. It shows the top ranked issue for each of the six Delphi questions and exemplifies how all issues were treated during the conceptual solution generation phase. The matrix essentially depicts a semi-structured brainstorming process, undertaken using the Delphi results as stimuli for design ideas.

Discussion

The results from the six questions are discussed separately below. This is because, rather than constructing general theory about the participants' perspectives of SAT, each question was designed to have a different practical application. Relevant literature is also presented and used for comparative analysis.

Issues relating to SAT malfunction

The most crucial results from the first question were mechanical and related to robustness. To address these issues, robust alternatives to systems prone to malfunction are required. AT literature does not provide contemporary information about problematic elements of SAT, so solutions have not been published. However, design engineering literature reflects a number of the issues and offers possible solutions. For example, Design for Manufacturing and Assembly (DFMA) techniques could solve the problem of small parts getting lost by proposing multi-functional part design and minimised part numbers.

Reasons for SAT malfunction

Responses to the second question help determine the context of SAT failure and malfunction. Again, SAT devices were found to lack robustness. Another interesting issue relates to dirt build-up, which causes keys and buttons to get stuck. Though not rated highly enough to be listed as crucial, participants noted a lack of instructions around decontamination procedures for SAT and difficulties with infection control when devices are shared. All of these issues provide a strong case for SAT that can be more easily cleaned or is more resistant to dirt. Here, solution generation could lead to devices that are dishwasher safe, employ hydrophobic or oleophobic coatings, or are encased in a membrane which can be easily disinfected. Like the first question, there is little evidence of this type of data in the literature.

Characteristic variables of an end-user associated with SAT use

The results of the third question inform the designer about functional elements of SAT that should be customisable. The large number of results suggests that in order to design an appropriate SAT device for a range of users, features should primarily be inclusively or universally designed and only when this is not possible should they be customisable.

The characteristics can be broadly categorised into physiological, emotional, and contextual. Range of motion, muscle tone, tremor, fine motor control, strength and vision, along with cognitive ability and the presence of pain all relate to physiological function. Motivation, level of interest and stamina are emotional issues. Contextual issues relate to the type of activity facilitated by the SAT, the environment of use, and the support which the user has. Three of the 25 issues did not directly result from the Delphi study, but were added from previous studies [4, 57]: verbal ability, hearing and experience with computers.

The results of this question reflect and are supported by Hoppestad's [4] Delphi study, which provided a list of elements for computer use assessment; Arthanat et al.'s [57] study, which listed ‘user abilities and skills’; and Danial-Saad et al.’s [58] Delphi study, which presented an ontology for physically controllable pointing devices. These previous studies were undertaken to assist comparative device analysis and aid AT selection. However, by using this type of information during the development of customisable AT, a designer can attempt to create AT solutions which facilitate use by individuals with various levels of muscle strength, visual acuity or range of motion.

Though measurement range data is not available for many user characteristics, awareness of the variables during concept generation could help to inform the development of adaptable solutions that are useful for a greater number of people.

End-user requests regarding AT use and training

The results of the fourth question emphasise the holistic approach required for satisfactory device adoption and suggest that contemporary technologies should be exploited to make product use and training more efficient and satisfactory. Conceptual solutions might lead to the provision of demonstration videos about how to assemble, use, modify and clean SAT, or the establishment of specialised online peer networks for sharing SAT information.

Professional users’ perceptions of end-users’ SAT preferences

Thirty three issues provide criteria to inform development of the product package. Two issues were added from other studies in the literature: the need for the SAT to be safe [59, 60] and environmentally sound [50]. The results of the fifth question echo previous studies and add contemporary data. Batavia and Hammer’s [19] seminal study involving people with disabilities generated a list of consumer based criteria for the evaluation of AT. Twelve criteria from that study are reflected in this research. Batavia and Hammer acknowledged that the study was preliminary in nature due to the small sample (n=12) not necessarily representative of the population and that the criteria were not tested for validity and reliability. Still, their study [19] is cited regularly in the literature and has been used as part of an AT framework [57]. The sample described in this paper is not considerably larger but as it was composed of professional users rather than end-users, the similarity between the results helps to validate both pieces of research.

Scherer and Lane [60] produced categories for assessing consumer profiles of ideal AT. These all echo Batavia and Hammer's [19] results and those generated in this research. Arthanat et al.'s [57] Usability Scale for AT (USAT), Hoppestad's [4] Delphi study, as described above, and Danial-Saad et al's.[58] list of device features also support the results of the fifth question in this Delphi study. One point about these previous studies is that, although the criteria are useful in a broad sense, instructions on how to apply them in a clinical or real-life setting is less clear. Batavia and Hammer [19] noted that studies in the past had resulted in issues about how AT was regarded by users and why AT was purchased and abandoned, but not on how they should be designed, manufactured and selected. The studies mentioned above succeeded in generating and collating this type of information, but they did not then propose a way of applying the criteria in the design process of new devices. The approach described in this paper addresses this by providing specific guidelines and recommendations for the translation of user input into technical solutions by means of a morphological matrix.

Feedback to the fifth Delphi question highlights thirteen new design issues not evident in previous studies. These tended to relate to modern technology trends such as the desire for wireless operation, universal connections and batteries that can be easily recharged. Research related to other types of EAT highlight similar design issues. Hersh and Johnson [61] carried out a multi-national study to examine users' attitudes and preferences relating to robotic guides for blind people. Responses revealed contemporary technological desires. Baxter et al. [62] reviewed literature concerning barriers and facilitators to the use of augmentative and alternative communication devices. Reflecting the results of this Delphi study, they found that ease of use, reliability and service provision are important. Certain issues resulting from the fifth question can be considered in parallel with the third Delphi question about user characteristics. For example, desirable criteria such as appropriate sensitivity, size or weight highlight the fact that different features need to suit different end-users' needs. For instance, a person with advanced muscular dystrophy may require a smaller, lighter, more sensitive switch than someone with hypertonia or cerebral palsy. These ideas may consequently lead the designer to generate concepts whereby the sensitivity, size and weight of a device can be easily adapted.

The results of the fifth question can also be seen to relate to the criteria generated in the first question. To explain, desirable qualities like durability and portability are useful concepts when comparing devices during prescription, but they can also serve as overarching recommendations for new products. However, to tangibly realise these types of traits, solutions to defined problems must be developed. Though it is clear that devices can be made more durable with tougher materials, less evident solutions become apparent when specific problems related to durability are revealed. For instance, highlighting that SAT cables tear offers a specific problem to solve, thus shaping a clearer path to a durable design.

Professional users' frustrations with SAT

Results from the sixth question illuminate real-life use contexts and the associated issues, again providing the designer with specific problems to solve. The results of this question also highlight the need for designers to consider AT devices as holistic systems that interact with other devices, systems and environments, as well as the user. Many of the results support the fundamental aims of the research. The need for low cost AT is reflected in frustrations about the high cost of SAT, access to funding, the cost of repair and short warranties. The idea of mass customisation is supported by responses about the difficulty of adapting devices for individuals' needs, the desire for SAT devices which can be modified with changing user requirements, and the problems with specialist/niche products.

The intention of this research is that the Delphi study format will be used during the development of other types of AT. To consider how this could work, the design of a customisable walking aid is envisaged here. The first question related to device malfunction would likely raise issues about handles on crutches and walking sticks, or wheels and brakes on rollators. The second might result in issues about product use on difficult terrain such as slippery surfaces or steps. The third question might show that end-user characteristics like physical fitness and balance are important. An issue about physical exercises that could improve device use might result from the fourth question. Desirable traits of a walking aid may relate to ergonomic handles or easy device storage when travelling. The sixth question might highlight frustrations associated with repeatable height adjustment settings or crutches being disposed of poorly.

Conclusion

The purpose of this research was to construct and demonstrate a method to develop better AT and ultimately reduce the associated cost, waste and frustration. To begin to address these issues, a method to involve professional AT users in the design process of customisable AT was developed and described here. This research aims to provide a tool that is participatory, but also relatively economical and easy to implement. The approach recognises the experiences and knowledge of people working in the field of AT and demonstrates a way to translate this information into product design specifications. Selecting the most appropriate concepts is a separate phase and further processes involving end-users with disabilities are underway.

This research acknowledges that technology is a rapidly evolving domain and that AT developers should benefit from mainstream technology innovation. Although the literature is rich with studies promoting generic desirable criteria for AT, this research argues that regular and contemporary updates about issues that users experience would be useful. This research highlights that at the front end of new product development, explicit data about experienced frustrations related to AT can help to generate new solutions. Essentially, stating that a device should be affordable and durable is valid, but presenting a designer with a problem to solve facilitates more efficient solution generation and helps to bridge the gap between the need for more durable devices and a tangibly more durable device. This reflects Cross' suggestion [63, 64] that the creative event in design is like the building of a bridge between a problem and a solution through the identification of a key concept. Schön [65] supports for this idea by suggesting that in order to solve a problem, designers must frame the design situation by setting boundaries and selecting particular things to resolve [66].

This research found that user characteristics are not only valuable data during AT evaluation and prescription, but can also be applied to the design process of customisable or universal products. Exploring user characteristics related to SAT use and desirable criteria for SAT may appear superfluous given the rich history of such studies [4, 58, 67]. However, because technology is an ever evolving domain, new device features and different user characteristics are likely to become relevant. For example, in the case of SAT, brain computer interfaces may become more ubiquitous, so a user's willingness to have neural signals read might be a user characteristic or the type of scalp interface might become a device feature. For this reason, continuous regeneration of desirable device criteria and relevant user characteristics is proposed as useful.

To conclude, this paper has described and demonstrated a method to generate and utilise crucial design issues for specific AT domains. The Delphi study highlights desirable product traits, relevant user characteristics, experienced problems and user frustrations related to the AT domain. The morphological matrix then structures the use of these issues as stimuli for concept and solution generation. This research builds on previous AT studies [4, 19, 57, 58, 67] and frameworks [5, 54, 55] and has attempted to develop the associated theories into a practicable design tool. Reinforcing the cross-disciplinary and knowledge sharing culture of the AT research community, the intention of this research is that the presented method will be adapted to generate and share contemporary crucial design issues about other AT domains.

Limitations

Semantic clarity is a limitation in the Delphi study as definitions were not provided in the second questionnaire. Accordingly, participants may interpret the meaning of the design issues differently. Additionally, robust validation of the proposed benefits of the described design method would require a complete product development case-study in a commercial setting. Although technology transfer is a key factor in measuring the success of a new product, this research advocates that the front end of the design process should primarily be user-centred. The research purposefully does not involve AT manufacturers or commercial organisations because, although stakeholders in the AT domain, they are not technically users of AT. As a result, it was deemed that commercial biases related to cost, precedent products and perceived feasibility could impact negatively on the user-centred research outcomes. Finally, the method application described in this article was carried out by the principal author, rather than independent designers in an industrial context. Concepts generated in the morphological matrix are inherently a product of both the Delphi study findings and their interpretation by the researcher. This interpretation is coloured by their background knowledge and design style. This may be seen to reduce the scientific validity of a conceptual design result, but the authors argue that this human element is necessary for creative innovation. Bearing this in mind, the example in this paper should be viewed as a demonstration of how the Delphi study and morphological matrix can be applied, rather than a test of the method's efficacy.

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Declaration of Interest

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Delphi questionnaire		Morphological matrix			
Data generated by participants		Interpretation of data and translation to design criteria by the designer			
		Design Issue	Relevant Component	Product Relevance	Design Solutions
Stimulus statement	**Durability, dependability and reparability are traits that relate to the longevity and functionality of an AT device (X). When an X (e.g. special access technology device) breaks or stops working, it can have a negative effect on a user's relationship with their technology.**				
Question 1A	If you have witnessed X failure, or have had to request or carry out maintenance on such a device, please list the most prevalent parts of the device that require attention. You may also mention parts specific to a particular type of X.	Prevalent parts of an X that malfunction. (Issue 1, 2, 3...)	?	?	Ways to reduce or negate the issue. (idea 1A, 1B..., 2A, 2B..., 3A, 3B...)
Question 1B	If you are aware of reasons that have caused an X to fail, please list these reasons.	Reasons Xs malfunction or fail.	?	?	Ways to reduce or negate the issue.
Stimulus statement	**Flexibility and customisation are ideas which attempt to accommodate the changing needs of a service user by reducing the need for device replacement.**				
Question 1C	Please list the key characteristics you associate with a service-user's abilities and an X. These may be the variables you look at if you carry out AT or disability assessments.	Characteristics of a service-user associated with selecting an X.	?	?	Ways to make the product customisable with regard to the user characteristic.
Stimulus statement	**Simplicity, learnability and operability are terms which relate to AT use. Simple, successful operation of an X is important for user satisfaction, but training is often required to facilitate this.**				
Question 2	What are the requests or needs which you are asked to facilitate with regard to X use and training?	User needs regarding X use and training.	?	?	Ways to enrich the product package.
Stimulus statement	**Effectiveness (the extent to which an AT device enhances functional capability or independence) and personal comfort are examples of traits of AT that impact upon user preference and acceptance of AT.**				
Question 3A	Please list what you perceive to be desirable traits of an X in relation to user preference. Please be as specific as possible.	Desirable traits of an X.	?	?	Ways to enrich the product package.
Question 3B	If you, in your personal professional capacity, experience any frustration with Xs, i.e. when selecting, assessing, training, affixing, removing, cleaning and so on, please list what frustrates you.	Participants' frustrations associated with Xs.	?	?	Ways to reduce or negate the frustration.

Appendix 1: Adaptable Delphi Study and Morphological Matrix

Appendix 2: Crucial design issues for SAT, i.e. ranked Delphi study results

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Issues relating to prevalent parts of an SAT device that malfunction

1. Cables wear, break, twist, fray or tear.
2. Connections between the cable and the SAT wear.
3. Touch screens stop being responsive.
4. Devices have calibration problems or are difficult to calibrate.
5. Conflicts exist between the computer and SAT driver.
6. Small parts get lost, e.g. clamping screws.
7. Mounts loosen.
8. USB and other ports break.
9. Internal electrical switch contacts fail.
10. Sensors fail.
11. Movement of SAT becomes restricted due to dirt build up.
12. Keys/buttons lift away from SAT.
13. Lightweight switches are continuously accidentally activated and break.

Issues relating to the reasons SAT devices malfunction or fail

1. SAT falls/is knocked or banged.
2. Inappropriate, rough and over-use of device.
3. Cables get caught or are pulled roughly from ports.
4. SAT undergoes general wear and tear.
5. SAT is poorly maintained.
6. Battery conditioning practice is poor.
7. Weak joints connect cables to device.
8. Battery life or charge is insufficient.
9. Batteries fails.
10. Software updates conflict with SAT device drivers.
11. Poorly routed cables are exposed to damage.
12. Dirt, spills and dust contaminate the SAT.
13. Movements of client cause mounts to loosen.
14. SAT is poorly cared for when not in use, e.g. during transport.

Issues relating to the characteristics of a service-user associated with selecting an SAT device

1. Range of motion of the anatomy which controls the SAT
2. Spasticity/muscle tone
3. Tremor
4. Control of movement, i.e. ability to make precise movements
5. Ability to repeat a movement without strain
6. Motivation and level of interest
7. Posture and client’s position
8. Wrist and finger function, i.e. dexterity, sensory perception, proprioception
9. Physical stamina
10. Cognitive ability
11. Condition progression, i.e. improving or degenerating
12. Activity to be facilitated by the SAT
13. Environment the SAT is used in
14. Presence of pain
15. Concentration and attention
16. Grasp
17. Speed of movement
18. Muscle strength
19. Access to technical support
20. Funding constraints
21. Vision
22. Service user's level of independence
23. Service user's social network and their familiarity with the technology
24. Type of wheelchair being used, if one is used
25. What the SAT will be mounted on and the requirements for clamps and mounts

Issues relating to service-user's needs regarding SAT use and training.

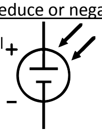
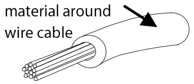
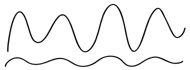
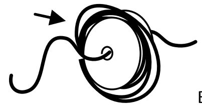
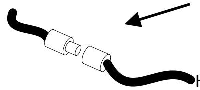
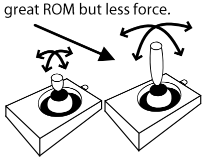
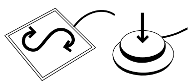
1. Correct positioning and mounting of the SAT
2. Access to SAT for trial period
3. Instilling the motivation to practice, explore and use the technology
4. Simple, written instructions for the set-up and use
5. Pictorial instructions for set-up and use
6. Maintenance and care instructions
7. Information on how to adapt the SAT for the service user's changing needs
8. Contact details of supplier and technical support
9. Instilling confidence in the service-user
10. Involvement of the service user's social network in training procedures, e.g. family/carers/teachers
11. Reviews of equipment
12. Basic IT training
13. Provision of demonstrations
14. List of frequently asked questions for troubleshooting
15. Recommendations for use in educational settings, i.e. for school staff and boards
16. Introduction of the service-user to individuals who have experience of the SAT
17. Specific training around a task or feature
18. Regular meetings with the service-user

Issues relating relate to desirable traits of an SAT device.

1. A good match between service-user's goals and the SAT solution
2. Comfortable to use and does not cause strain
3. Does not impede movement of service-user
4. Adaptable to service-user's specific needs
5. User-friendly
6. Reliable
7. Easy to set up and dismantle
8. Long battery life
9. Easily rechargeable battery
10. Easy to operate
11. Re-adjustable
12. Attractive aesthetics
13. Sensitivity
14. Design is based on mainstream devices
15. Social acceptability, i.e. a design that doesn't make the user stand out
16. Versatility/flexibility/capability of the SAT to be multi-functional
17. SAT is intuitive to use, e.g. software should have clear menus
18. SAT comes with clear instructions
19. Easy to maintain
20. Durable/robust/sturdy
21. Quick to turn on
22. Easy to position
23. Has a universal connection, i.e. USB
24. Appropriate weight
25. Quick to install
26. Compatible with different operating systems
27. Up-to-date
28. SAT provision is paired with access to local providers who can supply training, maintenance and repairs
29. Appropriate size
30. Appropriate tactile characteristics
31. Low cost
32. Portable
33. Wireless operation

Issues relating to frustrations associated with SAT.

1. The high cost of SAT and access to funding for purchasing
2. Positioning in a multi-care environment, i.e. clamps and mounts need individual adjustment for each user and this is difficult to replicate
3. Limited access to customer support/technical assistance/product manufacturers
4. Cost of repair and short warranties without additional payment
5. Discrepancy of funding throughout the country
6. Time needed to repair devices, leaving disabled users without technology
7. Devices are not "plug and play", e.g. drivers need to be loaded from CDs
8. The system is not easily adaptable for suiting exact service-user needs
9. SAT needs to be modified for changing service-user needs
10. SAT positioning
11. Lack of follow through by families and schools
12. Time needed to assess and train service-users
13. Products are specialist or niche

Design Issue	Relevant Component	Definition/Function	Design Solutions				
Question 1: These issues relate to prevalent parts of SAT which malfunction.			Ways to reduce or negate the design issue				
Cables wear/break/twist/fray/tear.	Cables	Transfer power and transfer signal.	 Take out cables & use wireless technologies (rechargeable batteries/ solar power/infrared transmitter and receiver).	 Use robust insulating materials to reduce likelihood of damage to cables.	 Make cables very rigid/flexible to reduce likelihood of torsion and breakage.	 Eliminate loose excess cable by retracting or winding/tucking it into a clip.	 Have purposeful ‘breaking point’ along cable which can be reconnected; cable is less likely to tear or damage ports and jacks at the computer interface.
Question 2: These issues relate to the reasons SAT malfunctions or fails.			Ways to reduce or negate the design issue				
SAT falls/is knocked or banged.	Housing/Casing	Protects internal components and affords aesthetic qualities to the product.	Protect SAT in robust casing.	Fix SAT on mount to reduce the likelihood of an accidental fall.	 Use a flexible material with low Young's modulus for casing to endure bangs.	Make all individual parts robust for disassembly, i.e. build in the ability for the SAT to be broken apart and easily put back together.	
Question 3: These issues relate to the characteristics of a user associated with selecting SAT.			Ways to make the product customisable with regard to the design issue				
Range of motion (ROM) of the anatomy which could control SAT.	Physical interface where human movement is required to activate device; joystick lever, switch button, trackball etc.	Distance hardware component needs to travel through to activate device.	Use various materials with different rigidity for adaptive customisation. (Work = Force X Distance)	 Forms requiring different activation distances.	 Use different base devices which require either a small ROM (touch-pad) or a large ROM (selection of switches).	Use an easily maneuverable mount which can position the SAT at various distances from the individual.	
Question 4: These issues relate to service-user needs regarding SAT use and training.			Ways to enrich the product package				
Correct positioning and mounting of the SAT.	Mount and mount-interface	How the therapist arranges the SAT in proximity to the user.	 Obviate need for mount - user wears SAT.	Provide an easily adjustable and re-adjustable mount. Use quick release levers and colour/number coded shafts.	Use shape memory alloys for mount material.		
Question 5: These issues relate to desirable traits of SAT.			Ways to enrich the product package				
A good match between disabled user's goals and SAT solution.	Whole product package	How well the SAT satisfies the user’s goals.	Make the device adaptable/customisable.	Find out goals and provide solution using observation and team participation.	Use list of questions and tests to determine best SAT.	Provide a trialling period for new SAT.	Facilitate follow-up sessions and online feedback forums.
Question 6: These issues relate to your frustrations associated with SAT.			Ways to reduce or negate the frustration				
High cost of SAT and access to funding for purchasing	Whole product package	Monetary cost of the SAT.	Increase lifetime of product, i.e. build in the ability for the SAT to adapt with user’s changing requirements.	Use off the shelf parts; examine other devices for component lists.	Increase market share by mass customisation or universal design.	Reduce overall cost of AT to the user by reducing abandonment.	Implement Design For Manufacture and Assembly guidelines (DFMA).

Appendix 3 Adapted Morphological Matrix