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Devices for Assisted Living

Deliverable 6.3

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Dissemination Level

PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Contents

Executive Summary

The purpose of this document is to present the results of the validation of the DALi project made during several experimentation trials. The validation has taken place in two different locations involving more than 34 users overall. The blueprint for the experimentation phase was set in DR 6.1, where we have specified the type of experiments, their duration, the target population and the way we dealt with ethical issues. The testing and experimenting activities involved more than 50 people overall. The experimentation phase also include a roll-out day in which the system was shown to the local press and to the public authorities of the autonomous province of Trento. In this deliverable, we report a short description of the system configuration tested in the different scenarios, the technical lessons we could learn from the experimentation, as well as the qualitative and quantitative results that we could collect from the users involved.

Chapter 1

Introduction

The experimental validation of the system capabilities was an important activity that absorbed a considerable effort from the different partners during the whole third year of the project activities. The experimentation was planned in a Project meeting in Trento in May, with the participation of all relevant partners in the consortium. It was agreed that:

1. The core of the experimentation activities would take place in Ciudad Real in September 2014;
2. The population of involved users would be split between older adults and care givers in the same proportion;
3. The emphasis of the experimentation would be on the guidance and on user interface abilities;
4. The experimental scenario would replicate as much as possible a real-life shopping centre scenario;
5. A through evaluation with students and technical staff would be made prior to the experimentation with real users to fine–tune the different design parameters;
6. An exact description on the functionalities to be tested, on the ethical protocols, on the metrics would be made in the context of DR 6.1, submitted to the ethical committee of the University of Northumbria and then pushed through the local ethical committees in the weeks immediately after the meeting.

In addition it was decided that the features of the systems left out of the experimentation would be integrated and tested in a demonstration day in Trento, to be held in October 2014. This experimentation would give us the opportunity for an official roll out of the project, with a press conference and a presentation to the local authorities. One possibility that was left open in the discussion was to have an additional experimentation phase in Trento, taking advantage of the opportunity of the presence of a simulated scenario. We followed up the meeting with a sequence of actions that lead us to a successful completion of our agenda. Specifically,

- We have released D6.1 with all the details of the experimentation clearly
- We have completed the implementation (Deliverable D5.3) and fine-tuned the integration of the functionalities requested for the experimentation; the integrated prototype was released as Deliverable D6.2 in its due date;
- The testing of the system functionalities was carried out with the involvement of 20 subjects between students; this activity allowed us to fix several bugs in the software and to fine-tune the parameters of the guidance algorithms;

- We obtained timely clearance of the Ethical Committee of the University of Northumbria and of the Consejeria De Salud y Bienestar Social de Castilla-Mancha, which is responsible for the residence in Ciudad Real where we planned to recruit the users.

After this preparation activities we were in condition to start the experiments in Ciudad Real. A group of 8 care givers and 13 older adults resident in La Ciudad de Matrimonios Ancianos Nuestra Señora del Carmen evaluated a selection of functionalities of DALi's s c-Walker within the Indra facilities in a simulated scenario. We tested different options for guidance, with a quantitative and qualitative evaluation made by the users. In late October we executed the planned roll-out of the system in Trento putting on display the system with all of its functionalities. This gave us the opportunity to show-case the system in operation to the Press and to the Local authorities of Trento and to collect video footage, which was used to produce a small video that can be presented to charities and potential users to collect additional feedback. Given the opportunity of a having a simulated scenario installed in the premises of the University of Trento, we decided to replicate the experiments made in Ciudad Real with an additional cohort of 12 older adults and 2 care givers. In Section 2, we will quickly discuss the different components of the system and report for each the level of integration, the validation activities and our technical considerations on the current state and on its possible developments. In Section 3, we will describe the experimental activities conducted on the system as whole and report the users' evaluation.

Chapter 2

Technical Validation of the Components

The DALi systems consists of the modules depicted in Figure 2.1. In this section we review each of the module, say how it was validated and discuss the outcome of the validation from a technical view point.

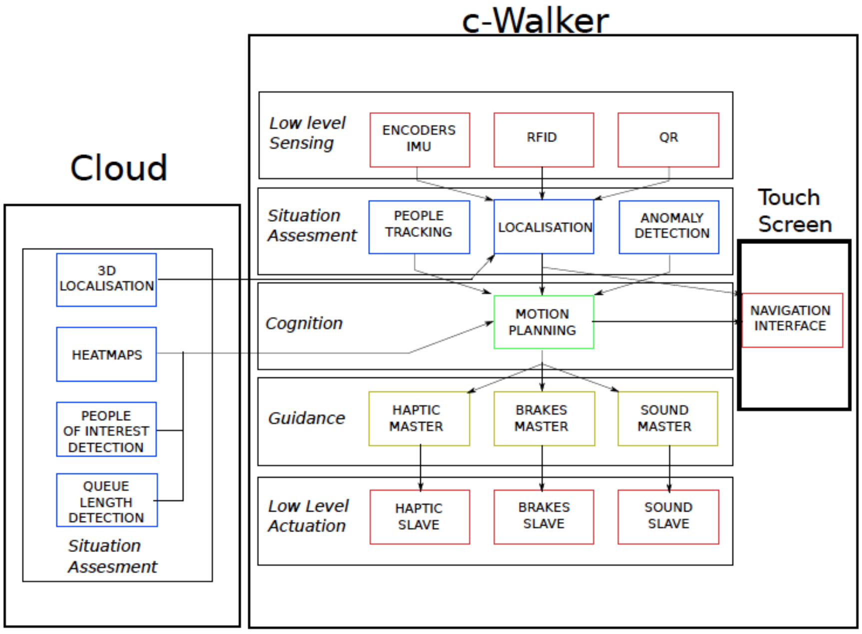


Figure 2.1: Functional diagram of the system. c-Walker internal and external modules

2.1 Situation Assessment

2.1.1 People Tracking

The short range people tracking module was integrated early on with the short range planner on-board the walker. Its objective is to provide the position in time of the different humans in front of the c-Walker. This information is used to make prediction and produce short term plan.

Validation Type. The system was demonstrated during the ICT2013 exhibition in Vilnius, during the second year review meeting in Ciudad Real and, finally, during the final demonstration in Trento, in October 2014.

Evaluation. The algorithm proved itself robust enough; it is able to recover from tracking loss and can perform in environments with little 3D information by utilizing features detected in the colour stream. During testing, difficult scenarios where identified: Situations where there are too many moving objects in the field of view or when the walker is really close to an obstacle. In such cases the visual information does not suffice to infer the c-Walker motion and the method could benefit from feedback from the platform localisation module. Another important direction of work is to increase the sensing range. As of new, the system works reliably for targets 4 metres away from the c-Walker. Beyond this range, the incoming data become too noisy. We expect that with the next generation of Kinect sensors this problem could be solved.

2.1.2 Anomaly Detection

Our anomaly detection system is based on the detection and on the interpretation of warning signs.

Validation Type. Reading of warning signs has been successfully demonstrated at various locations, i.e. the EC ICT event in Vilnius, the 2nd year review in Ciudad RealÂ as well as during the final experiments conducted in Trento.

Evaluation. Outcome of the anomaly detection has been integrated and successfully synchronised with other DALi modules (i.e. the motion planning) resulting in a prototype setup that shows the successful communication of event detection between two walkers. During the final experiments we did recognise that specific artificial lighting seems to influence our system, as well as some tuning needs to be done on the OCR component while the detection and localisation steps seem to work very robust.

2.1.3 Detection of people density

Heat maps are directly connected with the Long Term Planner in order to provide it with occupation maps in the sense of people crowdness.

Validation Type. Heat maps integration and communication with the c-Walker has been successfully demonstrated both in the second year review meeting held in Ciudad Real as well as in the final demo in Trento.

Evaluation. The minor issue to be improved in this application is the correction of the radial distortion that suffers the image taking into account that we are working with 360 degrees cameras to cover a big area. The occupation map is calculated after the rectification of the captured image of 360 degrees so in this process objects are already distorted. Even we have proven good results for crowdness estimation and its application together with the long-term planner in order to choose the best routes, it is foreseen as a future working line to achieve more accuracy in the estimations.

2.1.4 Detection of People of Interest

People of Interest are detected through the surveillance cameras and are identified based on particular hats or of colour patterns of their uniform. This information is immediately broadcast to the users through the middleware, an it can potentially be used by means of an easy to use button permanently on the screen in case the user requires assistance.

Validation Type The system was shown in Ciudad Real during the second review meeting. An improved version has been tested and demonstrated during the demonstration day in Trento.

Evaluation. The tests carried out in Ciudad Real during the second year review meeting made us realize the importance of lighting when processing the information, since the Kinect sensor must work with indoor light. The facilities used in Ciudad Real had the problem of sun's reflection, which sometimes produced dark images that could not give colour information to extract the body print of the person. Another feature to take into account in people of interest detection is the location of the Kinect camera in such a way that we must calibrate the system once the camera is installed, i.e. to extract the body print for each people of interest we want to look for (policeman, staff or shopping assistant . . .). With these assumptions the system has been integrated with the rest of modules of the DALi project and successfully demonstrated in the last demo conducted in Trento. The communication with the Long Term Planner worked fine and the walker was routed to the person of interest the user selected.

2.1.5 Queue Length Detection

In a shopping place the information on the current queue length can be of fundamental importance for a senior user to decide which place she/he should visit. Our queue length module uses Kinect sensors places on the access point to any point of interest.

Validation Type. The system was demonstrated during Year 2 review in Ciudad Real. An improved version has been shown during the demonstration day in Trento.

Validation. During The queue length detmoection was implemented using Kinect cameras and it was firstly demonstrated in the second year review meeting in Ciudad Real. In that moment Y2 review meeting the system t was tested with several people lines in elevators and in toilets and the system provided two parameters refreshed in real time: the number of people in the queue line and the length of the queue in metres. The system has been progressively improved, integrated with the Long Term Planner and successfully demonstrated in the final experiments performed in Trento. At the final integration, the information served to the c-Walker was the number of people standing in the line, which was shown in the user Android tablet to allow the user decide where to go depending on the number of people in each toilet, shop or elevator.
Additionally, our system can give the statistics of all the different queues in the scenario based on the number of people, the length of the queue and the time of service regardless the type of queue. This information is saved in real time in a database and we have developed some web services and a web interface where this statistics are shown at each moment (see Figure 2.2).

2.2 Localisation

2.2.1 Use of Odometry and of Markers

The primary technique that we used for localisation is based on the combination of a relative position system (which tracks the position of the user starting from a known point), with an absolute localisation system based on the detection of markers (RFID tags and QR codes) deployed in the environment.

Validation Type. This localisation system was validated during the experimentation with real–users both in Ciudad–Real and in Trento. It was also tested during the final demonstration test in Trento.

Evaluation. The localisation system behaved satisfactorily, after a complex initial set up phase. The error was consistently below the acceptable bounds (a few centimetres). A known problem of the system is its reliance on a heavy infrastructure. In our current estimate, markers have to be no more than 10 metres apart one

Yelmo Cinemas - Queue Waiting Time: **7.5 min** / **12 people**

Figure 2.2: Example interface showing the queue length in different places in the shopping centre

from the other in order to have a satisfactory localisation accuracy, which could demand heavy infrastructure on the place-.

2.2.2 Visual Odometry

A by-product of the people-tracking module is visual odometry. The module tracks the motion of people in front of the walker and in doing so, it computes the motion of the walker. This visual-odometry information is used as one more cue for the c-Walker localisation module. It provides “incremental” information about egomotion along with a quality indicator. This could be used when the encoders and the IMU mounted on the device are not operational, or in system configurations where they are not used.

Validation Type. The system was validated during the final demonstration day in Trento During these trials, the visual odometry was deployed along with the other localisation modules in order to improve the robustness of the system.

Evaluation. A series of experiments where performed in order to quantitatively and qualitatively measure the performance of the localisation methods of the platform. Further tests must be performed in order to identify which combinations of cues provide good results in different deployment configurations. A comparative evaluation is under way.

2.2.3 3D localisation

We managed to develop an easy to set up localisation service that does not need any instrumentation or alteration of the environment besides the acquisition of a couple of images with a high-grade consumer camera. Performance characteristics of model based visual localisation have been significantly improved during the project runtime both in terms of localisation accuracy/stability as well as response time.

Validation Type. The system was validated and compared with other localisation options during the demonstration day in Trento.

Evaluation. Experiments conducted in Trento in a previously unseen environment verified that our solution gives a solid contribution for initialisation of the incremental localisation systems running on the walker thus keeping their drift low. We did come across an issue of the 2D camera sensor with respect to very noticeable motion blurring when utilizing higher resolution images. Nevertheless taking the image quality into account we did perform very solid, and for the future or similar applications the option remains to switch the camera sensor to one that does not suffer from rolling shutter and introduces less compression artefacts.

2.3 Motion Planning

2.3.1 Short Term Planner

The Short Term Planner, based on the social force model, was implemented at an early stage of the project. It has therefore been integrated in successive prototypes up to the present. It receives localisation information from sensor modules and receives an overall plan from the Long Term Planner. The key aspects of its performance are (i) its ability to dynamically guide the user away from fixed and moving objects and (ii) its efficiency (i.e., ability to function on lightweight portable hardware).

Validation Type. The module was validated in simulated scenarios during the demonstration day, where it was successfully integrates with the people tracker and with the long term planner.

Evaluation. In both simulated trials and user trials in quasi-real environments, the Short Term Planner has performed without problems. We are aware, however, that a real deployment may require greater performance to deal with more extreme crowding than we have so far tested. To improve (i) we have in hand the notion of ’behavioural templates’ to construct an enhanced version of the social force model. To improve (ii) we anticipate using already available high performance portable computing devices based on FPGAs or GPUs.

2.3.2 Long Term Planner

The Long Term Planner constructs an overall plan using an annotated graph data structure. The nodes and edges of the graph, together with their embedding, are derived from an efficient ’quad tree’ representation of the chosen environment. The user’s profile and goals are entered via the user interface. To construct each plan, this static information is augmented with current dynamical information provided by the DALi infrastructure (cameras and servers in the environment). In particular, the Long Term Planner considers ’heat’ (crowding) and anomalies (temporary obstructions).

Validation Type. A simplified version of the Long Term Planner (which identifies the shorted path between two positions) was tested with the users both in Ciudad Real and in Trento. platform for the final trials in Trento. The trials used Heatmaps and included plans with and without user constraints (preferences to be near or avoid certain areas). Anomalies were not tested, but have been tested in simulated environments.

Evaluation. The second version of the Long Term Planner sought to solve a important problem emerged during the pre-experimental phase: the trajectories produced were edgy and sometimes ran too close to the walls. In the experiments with the users these problems were apparently solved. No performance problems were encountered, nor are any foreseen. The planning algorithms are efficient and are called infrequently.
Open issues is to verify the realism of the user’s profile. In the current version, the user is allowed to express preference on staying away from the crowded areas, or on being always close to bathrooms and resting places. If this information is exactly what should be in the profile, and/or if other constraints would be needed is still

an open area for future investigations. Another important point is to have an appropriate interaction between short term and long term planner in the situations when the long term planner fails to identify viable routes.

2.3.3 Navigation Interface

The visual interface implemented for the touch screen included in the c-Walker has evolved as the main interface between the walker and the user. The motivation of this development is based in from the tests we made with users, which have shown that this interface give us the opportunity to show detailed information about the navigation process in a natural way and user acceptable way. After several interaction with the users it was decided that the visual interface should show information on route, destination, points of interest, etc. to the user through a friendly graphical view. The screens, which conform the mobile application, were developed over Android for tablets and it has been specifically designed for older adults ensuring the correct visualisation of the data using high contrast buttons, vivid colours, spatial differentiation of the functionalities, etc. The visual interface has been integrated with most of the modules developed for the c-Walker through its connection with the motion planning module that agglutinates the information from the path and the localization of the users, the risks position, the user emotion, the people of interest location, the queue length, etc. All this information is encapsulated through a set of messages and shown to the users accordingly, depending on the situation.

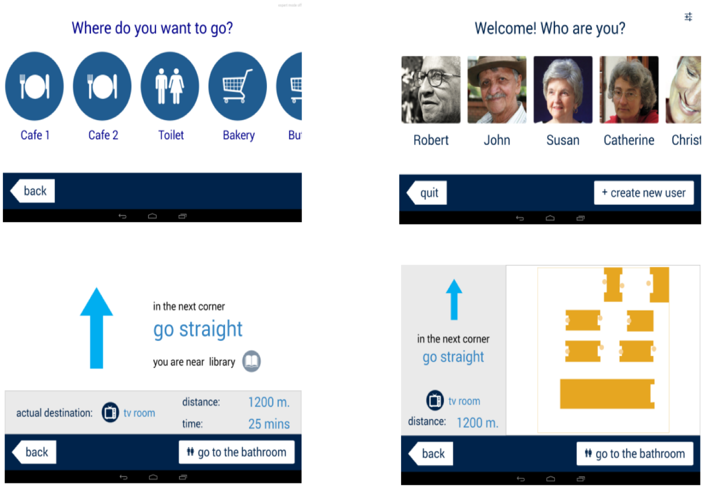

Where do you want to go?
Welcome! Who are you?
in the next corner
go straight
you are near library
actual destination: tv room
distance: 1200 m.
time: 25 mins

Figure 2.3: Screenshots of the visual interface

In the normal execution, the user can create his/her profile, select the destination that he/she desires and navigate through it with two different possible navigation screens selected depending of his/her abilities. The route is calculated taking into consideration the heat maps and the risks. Besides before initiating the route, if the destination has a queue, then the number of people waiting is shown to the user in order to notify before the start of the movement. During the navigation, the user is notified with the possible risks, performing a re-planning automatically of the initial route to avoid the dangerous situation. The user is also notified when his/her emotion changes to a negative one. In any moment, the user of the c-Walker can request help from any person of interest, showing the route directly to the desired person, and or request a route to the closest bathroom and sitting station (See Figure 2.3)

Validation Type. The visual interface has been successfully tested in various locations: the EC ICT event in Vilnius, the 2nd year review in Ciudad Real, the validation held in Ciudad Real, and also in the experiments done in Trento.

Evaluation. The results of the interface design can be rated as substantially positive. More than 30 older adults, some of which illiterate in computer science, have successfully utilised the interface both for the selection of target place and during the navigation with a minimum training phase.

More problematic has been found to be the use of the “physical device” to insert the information with a finger touch. We have used a capacitive technology for the touch screen (which is common place in modern tablets and smart phones). Some of the user had some difficulties interacting through the tactile screen, because the conductivity of the fingers’ skin seemed to be not appropriate to the commercial capacitive layers. The main explanation is because the finger conductivity is reduced as the user is getting older, which causes temporal lack of responsiveness of the graphical interface. A natural direction of work could be toward the replacement of capacitive screen with a resistive one. This would offer a force feedback to the user. Also the visual interface can provide a haptic movement after each touch for informing the user about the interaction. The price to be paid for taking this option is limited, since the only real advantage of capacitive screens (multi-touch) is not really relevant for our application.

2.4 Guidance

2.4.1 Haptic Guidance

Haptic guidance is implemented through vibrotactile stimuli which are displayed to the user only when there is a large deviation between the actual position of the user and the desired trajectory. Additionally, we have used haptic signalling to notify to the user a turn in the next few metres.

The haptic stimuli are generated by two bracelets fitted to the arm just below the elbow, which seemed to be the best location to optimise the ability for the user to discriminate the different signals.

Validation type. The vibrotactile feedback has been successfully evaluated in pilot studies conducted in Newcastle as well as during the 2nd year review meeting in Ciudad Real. The system has been validated with the users and during the demonstration day in Trento.

Evaluation. The proposed haptic policy has been successfully integrated with the motion planning modules, showing the correct communication of directional cues to the user based on the desired trajectory. Future improvements aim at reducing the size of the bracelets and improving the design. The blue-tooth module is particularly critical for battery consumption and occasional difficulty of pairing and will require future optimisation.

2.4.2 Acoustic Guidance

The auditive interface is composed of an audio rendering software that reproduces binaural auditive stimuli in accordance to the computed path and to the head orientation. Head orientation is acquired by controlling an inertial platform (IMU) placed on top of fullÂsize headphone arches. The system has been successfully integrated on the cÂWalker.

Validation type. The audio guidance system has been demonstrated and tested on various occasions: during early experiments with students performed in Trento, in the last year review in Ciudad Real, for the experimentation with users both in Trento and in Ciudad Real, and during the final demonstration day in Trento.

Evaluation, During early tests, we recognised that the system communicates more information with respect to what it is considered to be useful by test participants in order to localize the suggested path to follow. Therefore, subsequent tests were conducted with an audio rendering algorithm, which gives directional cues only in correspondence of decision points to the user, resulting into a simplified version with respect to what was initially implemented. On the final tests with potential users, we also removed the inertial platform on top of the headphone arches since we observed that with this solution, users are faster in recognizing the localisation information. For future similar applications, we can extend the amount of information displayed to the user by re-integrating the IMU, and rendering more complex auditory scenes. This solution can be more useful for users suffering from visual impairments. The interface can be improved by implementing the rendering of auditive paths instead of static directional cues. Moreover, during tests, users pointed out that wearing the headphone attenuates the perception of environmental sounds. To overcome this, it is possible to improve the interface by including the capture and reproduction of surrounding sounds.

2.4.3 Mechanical Guidance

Contrary to the guidance based on haptic and acoustic devices, mechanical guidance is based on an active role of the c-Walker that guides the user through gentle changes in the driving direction. For mechanical guidance the c-Walker can utilise two different actuators: the electrical brakes mounted on the back wheels or a stepper motor mounted on the front wheels. These actuators are used to implement a path following control algorithm. In the differential braking system, changes of directions are obtained generating different torques on the two back wheels. On the contrary, the steering front wheels are used in a similar way as with any car-like device. In both cases, DALi's approach is based on the idea of "virtual corridor". As long as the user stays in the middle of a corridor containing the path, he/she is given full freedom of motion. Guidance action becomes increasingly authoritative as she/he approaches the boundary of the corridor.

Validation Type. Guidance system has been tested with students in Trento. A subset of the guidance functionalities (using the front wheels) have been tested with users both in Ciudad Real and in Trento.

Evaluation. Pilot experiments conducted in Trento revealed problems on the braking system. The most important is the slippery surface of the floor that does not generate a sufficient torque to guide the system. The problem is not there when the c-Walker moves across rougher terrains. We believe that a viable strategy is to use stickier rubber mixture for the tyres, which we will do in a next release. Another critical problem was the reliability of the plastic gears engaged for the differential breaking action. The gradual smoldering of the gears reduced the efficacy of the system after a few runs. For this reason we decided to replace the gear with others made with a metallic league, which will be deployed in the future versions of the walker.
The guidance system using front steering wheels has been implemented and successfully evaluated during the final experiments conducted in Trento. The proposed steering policy consists in a mechanical stimulus which steers the wheels toward the desired path only for a short time. As a consequence, it "invites" the user to move toward a desired direction while the user is always in charge of the final decision. More aggressive guidance policies are under development.

Chapter 3

Final User Evaluation

3.1 Evaluation in Ciudad Real

3.1.1 Method

After receiving ethical approval for the study from Northumbria University and the local authority in Spain, the study was organised at Indra premises close to an elderly residence in Spain (“La Ciudad de Matrimonios Ancianos – Nuestra Señora del Carmen”), with whom prior arrangements had been made to support the evaluation.

3.1.2 Participants

21 Participants were recruited from an elderly residence in Spain (“La Ciudad de Matrimonios Ancianos – Nuestra Señora del Carmen”), 8 of whom were carers and 13 of whom were elderly residents. Elderly participants were aged over 60 years (mean age = 83), both male and female. These participants all took part on recommendation of the manager who verified their suitability to take part and their ability to give informed consent. Carers were aged between 33 and 59 (mean age = 46).

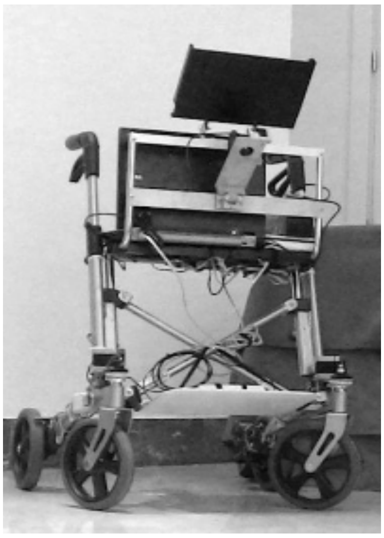


Figure 3.1: The c-Walker used in the experiments

3.1.3 Materials

During the study, participants were asked to use a c-Walker which was designed at the University of Trento. This c-Walker is shown in Figure 3.1. The walker has an intelligent system that maps out the progress of the user through a route and provides directions. These directions are conveyed to the user through a variety of modalities: visual interface (a tablet computer affixed to the front of the walker), audio interface (headphones worn by the user), haptic interface (wristbands worn by the user) and mechanical interface (turning the wheels gradually 30 degrees).

Figure 3.2: The test environment

The trials took place in a mock up of a shopping centre (see Figure 3.2). Four different, but equal distance routes were created, one to test each modality.

3.1.4 Procedure

Participants completed their consent forms and demographic and health questionaires prior to leaving the care home. They then commenced a short walk under the supervision of a carer to the testing location at Indra. A carer from the residence was present in the evaluation room for the entire evaluation to ensure the safety of the participants. Upon arrival, consent was verbally obtained to ensure that the participant was still willing to take part. The researcher who interacted most frequently with the participants was bilingual and ensured that all instructions were given accurately in Spanish and that participants' feedback was properly translated into English after the study.

Before starting participants received an explanation of the procedure. They then moved to the start of one of four routes and were given one of the four modality conditions to test (visual-only, visual-audio, visual-haptic and visual-mechanical). Directions were then presented to the participant via the visual interface along with another modality according to the condition. The time to complete a trial and any errors made were recorded for each trial.

The visual display is shown in Figure 3.3.

The display would count down the distance to the point of turn and at the point of turn would display a flashing arrow to indicate that the turn had been reached. Throughout the trial, participants were accompanied by the researcher who corrected them if they made mistakes.

After the first trial, participants completed a short evaluation of the modality and commenced a new route with a different modality (each route was the same length). Aside from visual-only, the other modalities were haptic,

quedan 3,4 m.

destino actual: 2

distancia: 25,6 m.

tiempo: 2 mins.

Figure 3.3: The visual interface used during the experimentation

audio and mechanical. The haptic modality required users to wear wristbands which vibrated at the point of turn in the corresponding wrist to assist the user. A user wearing these is shown in Figure 3.4:

Figure 3.4: User wearing haptic wristband

The audio modality required users to wear headphones which emitted a beeping sound in the appropriate ear when the user reached the point of turn. A user wearing these is shown in Figure 3.5

Figure 3.5: User wearing the headphone

The mechanical modality rotated the wheels thirty degrees in the direction of turn at the point of turn to assist the user. If the user pre-empted the turn, the motor was not activated. This system is illustrated in Figure 3.6.

Figure 3.6: Mechanical system attached to front wheels

Figure 3.7 provides examples of participants during the evaluation. After the user had tried each modality, they sat down and completed an overall questionnaire and were provided with refreshments. Figure 3.8 illustrates completion of a questionnaire. After debriefing, participants were led back to their accommodation and any further informal comments from the users were noted.

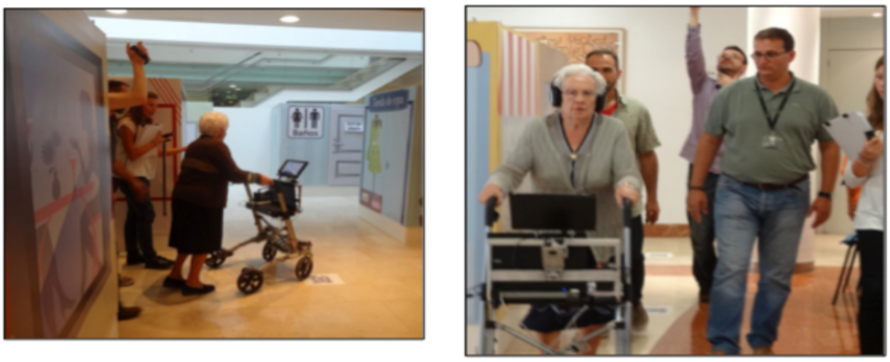


Figure 3.7: Users during the evaluation

Figure 3.8: Example of participant rating an interface

3.1.5 Results

Participants were asked to rate the ease of use, comfort, their confidence in using the interface and provide an overall rating of the system on a 10 point scale, where 10 was the best score. Table 3.1 shows a summary of the results of this evaluation. This suggests that the mechanical interface was perceived most favourably and the audio interface as least favourable. A repeated measures ANOVA was run to compare the ratings given to each of the interface components. Missing data was replaced by the mean. This was significant overall effect of the system on all the ratings. The significant pairwise comparisons are provided in Table 3.2.

Measure	system	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
ease	Visual	7.992	.379	7.202	8.783
	+ Haptic	7.381	.387	6.573	8.189
	+ Mechanical	8.429	.382	7.633	9.224
	+ audio	6.553	.619	5.262	7.844
comfort	Visual	7.912	.349	7.183	8.641
	+ Haptic	7.095	.425	6.209	7.981
	+ Mechanical	8.238	.384	7.438	9.038
	+ audio	5.503	.788	3.859	7.146
confidence	Visual	7.524	.363	6.768	8.281
	+ Haptic	6.190	.546	5.051	7.330
	+ Mechanical	7.857	.433	6.955	8.759
	+ audio	5.116	.746	3.560	6.671
overall	Visual	7.765	.442	6.843	8.688
	+ Haptic	6.190	.501	5.146	7.235
	+ Mechanical	8.048	.271	7.481	8.614
	+ audio	4.858	.701	3.396	6.320

Table 3.1: Mean evaluation scores for the interfaces devices

Measure			Mean Difference (I-J)	Std. Error	Sig.[b]
comfort	visual	audio	2.409	.833	.054
	mechanical	audio	2.735*	.893	.037
confidence	visual	audio	2.409	.857	.065
	mechanical	audio	2.742*	.878	.032
overall	visual	audio	2.907*	.712	.003
	haptic	mechanical	-1.857*	.553	.019
	mechanical	audio	3.189*	.770	.003

Table 3.2: Significant results for pairwise comparisons for rating measures

These show that there was:

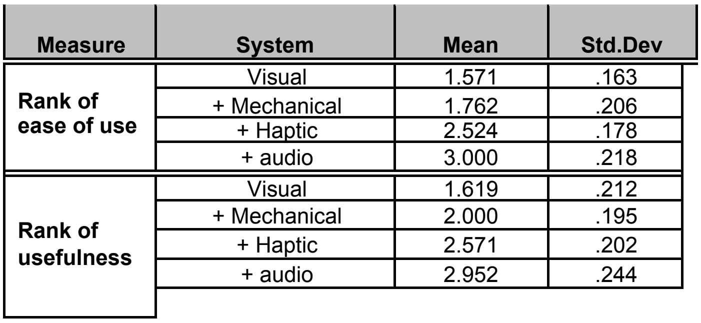
Ease of Use: No significant differences for the ease of use scores for each system

Comfort: The visual interface and the mechanical+visual interface were perceived as significantly more comfortable than the audio+visual interface.

Confidence: The participants felt significantly more confident in using the visual or the mechanical interfaces than using the audio interface.

Overall: The participants rated the visual and mechanical interfaces as better than the audio. The mechanical interface was also rated better than the haptic interface.

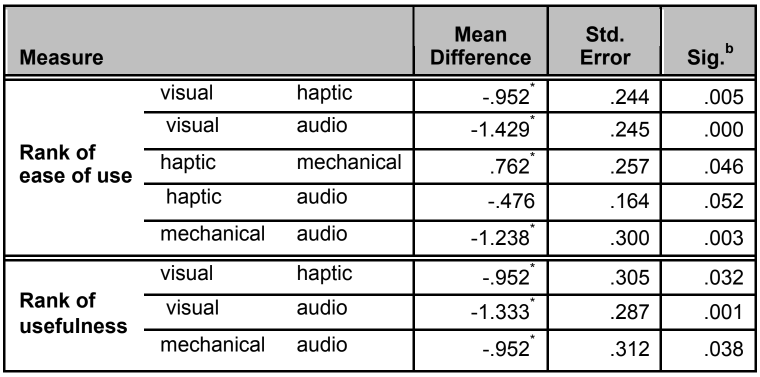
After using all four interfaces, the participants were asked to rank order the interfaces. While some managed to do this, others were happier rating one differently than the other three, i.e. "I like this one best but the others are all the same". If participants said this they were asked if their prefered option was a little better or a lot better, and all other systems were ranked 2 for a little or 3 for a lot. A repeated measures ANOVA was then carried out on the ranks scores. The mean value was assigned to any missing values. The means are provided in Table 3.3, where 1 indicates the most prefered on a scale of 1 to 4.



Measure	System	Mean	Std.Dev
Rank of ease of use	Visual	1.571	.163
	+ Mechanical	1.762	.206
	+ Haptic	2.524	.178
	+ audio	3.000	.218
Rank of usefulness	Visual	1.619	.212
	+ Mechanical	2.000	.195
	+ Haptic	2.571	.202
	+ audio	2.952	.244

Table 3.3: Comparison of rank ordering

Pairwise comparisons were then investigated and the significant differences are reported in Table 3.4. The main point of significant differences is between mechanical and audio interfaces.

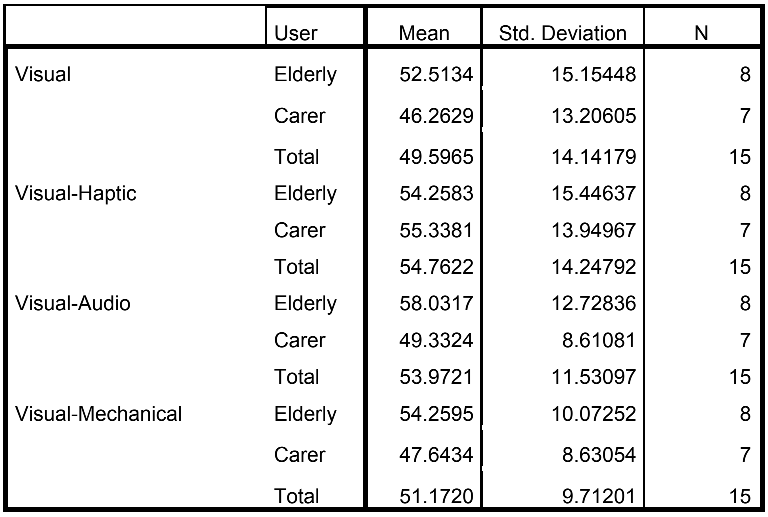


Measure			Mean Difference	Std. Error	Sig.[b]
Rank of ease of use	visual	haptic	-.952*	.244	.005
	visual	audio	-1.429*	.245	.000
	haptic	mechanical	.762*	.257	.046
	haptic	audio	-.476	.164	.052
	mechanical	audio	-1.238*	.300	.003
Rank of usefulness	visual	haptic	-.952*	.305	.032
	visual	audio	-1.333*	.287	.001
	mechanical	audio	-.952*	.312	.038

Table 3.4: Pairwise comparison significant results for rank order

Finally participants were asked to state their prefered system. In this case 10 /21 preferred the visual interface alone, and 9/21 preferred the visual interface with the mechanical interface added.

Data was also collected for the time taken for each route under each condition. A repeated-measures ANOVA was conducted to see if there was a main effect of condition on time taken to complete the routes. The results showed that there was no significant main effect. There was also no significant effect of user type (carer or elderly) and no interaction between user type and condition on time taken to complete the routes. The lack of statistically significant findings is probably because of the small sample size. Despite this deficit, we report the means below in Table 3.5 but acknowledge their limitations. This data is illustrated in Figure 3.9.



	User	Mean	Std. Deviation	N
Visual	Elderly	52.5134	15.15448	8
	Carer	46.2629	13.20605	7
	Total	49.5965	14.14179	15
Visual-Haptic	Elderly	54.2583	15.44637	8
	Carer	55.3381	13.94967	7
	Total	54.7622	14.24792	15
Visual-Audio	Elderly	58.0317	12.72836	8
	Carer	49.3324	8.61081	7
	Total	53.9721	11.53097	15
Visual-Mechanical	Elderly	54.2595	10.07252	8
	Carer	47.6434	8.63054	7
	Total	51.1720	9.71201	15

Table 3.5: Descriptive Statistics

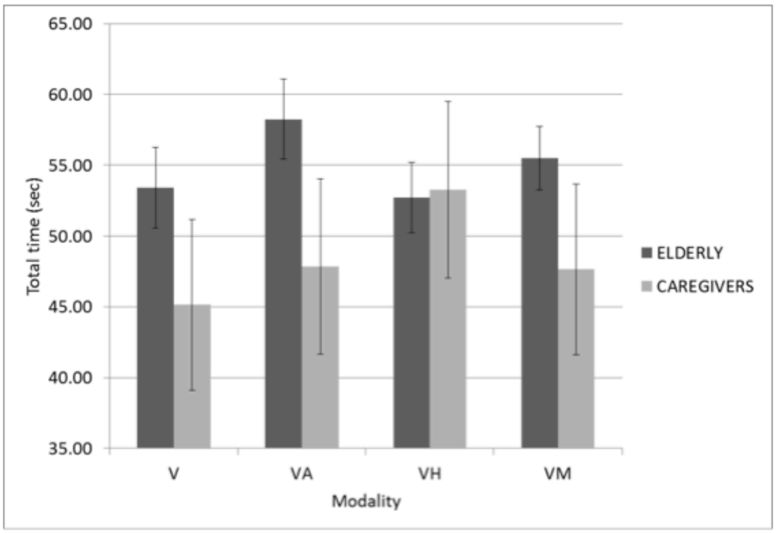


Figure 3.9: Graph showing descriptives for each modality

As expected, the carers performed faster than the older adults on all of the conditions with one unexpected exception. In the visual-haptic condition, carers were slightly slower than the older adults. However, because the difference is so small it is probably not important. The data shows that for the older adults, the fastest modality was visual-haptic, followed closely by visual. This difference was very small and not reliable. The slower results for the Visual-Audio and Visual-Mechanical modalities, while not reliable, may tentatively suggest that the visual condition alone is most suitable for older adults who may be distracted by the addition of other modalities.
We also analysed the number of errors made in each trial and found that there were no significant differences between the number of errors made in each modality.

3.1.6 Qualitative comments about the system

Visual Interface. The visual interface was preferred by some, for the simple reason they prefered the system to be as simple as possible, so if you had vision, you would use the visual system. They recognised that those with visual problems may require the additional interface eleements. Participants considered its role in preventing people from getting lost or distracted as illustrated by the quote below.
"*You can't get lost, you can be thinking about other things. If it directs you as you go, very good.*".
One comment was made about improving it by having audio (not through headphones) like a car navigation system to speak the instructions, another about improving the smoothness of the wheel motion.
Two comments were made about requiring additional functionality, one for a sound on arrival at destination and one saying that it would require better brakes.

Mechanical Interface. The participants liked the visual interface when combined with the mechanical interface. There was an additional, unplanned, benefit, that the noise of the brakes let the participants know that a turn was iminent. The participants liked this assistance to know when to turn, particularly if they were distracted.
"*I like it. It lets you know when you have to turn. It corrects you even if you make a mistake.*"
"*It's important, if you are distracted, it makes you turn.*"
They appeared to like the extra support with one participant describing it as being "*like an automatic wheelchair, but you can still walk, just with some help.*"
Though again, it was not perfect and some commented that the wheel sticks a bit.

Haptic Interface. There were more negative comments about the haptic system with participants reporting that it was *confusing, too tight, late, not comfortable, difficult to feel on bad arm, could be a little bit frightening* and basically that they did not need this in addition to the visual interface ("*You can do without it..* " *Overall: Its not necessary The arrows are big enough, they were easy to see. It's a bit uncomfortable to wear constantly, not good for daily life"*).
"*Why would we put it on, is it worth it or not?*"
Other participants were more positive, and felt that it acted as a reminder ("*When you feel it, you know you have to look at the screen. It reminds you*"..). they also felt it would be more appropriate for someone with a visual impairment.

Audio Interface. The overall reaction to the audio interface was negative. Participant felt that it was dangerous, isolating, uncomfortable, and "*Stops you being able to do other activities at the same time*" and only appropriate if you could hear well, in both ears.
"*Have to be very attentive, it's hard, because you have to to trust it. You disconnect, think about other things.*"
They did offer ideas as to how it could be improved. They felt that the system would be improved if spoken directions were provided in one ear rather than beeps to specific ears.

"*why not one ear and just say left or right*". "*Spoken directions, maybe in only one ear. Not so obvious*."
And they felt that it would be good for people with no vision.

Comments about visual system from researchers Overall the visual system appeared to work well, however there were a couple of points in the interaction that did not work as smoothly as the final system would require. The issues were associated with points in the interaction when two simultaneous instructions were the same, e.g. being told to turn left, then turn left. Participants did not notice that the instruction had been updated.
We had included flashing the turn indicator when a participant was close to the turn however the participants did not always associate the signal with the turn.

Feedback session to participants At the end of the evaluation session in Spain, a video was created which showed all the participants using the system and thanked them for their participation. Figure 3.10 shows the participants watching the video. This was followed by coffee, cakes and an informal thank you. The participants enjoyed receiving feedback and seeing each other. They hoped they had helped us in our research and wished us success

Figure 3.10: The formal presentation of the evaluation

3.1.7 Conclusions

In conclusion the participants rated the visual interface and the visual + mechanical interface as similar, with opinion split between the need for the addition of mechanical. From the participant qualitative comments, it was assumed that this preference was reflecting a desire to keep things as simple as possible rather than any problems with the use of the mechanical interface. This is consistent with the finding that the most simple system, the visual interface, was the fastest.
The haptic interface was rated in the middle, participants had no particular issue with it, but felt if they could use the visual interface alone they would prefer that. However, informal comments made by the participants suggested that they did not like the bands around their arms.
The audio interface was the only interface that was rated significantly worse than the others. The qualitative comments suggest that they found wearing headphones in public inappropriate as it cut them off from the surroundings.
There appeared to be an overall preference to keep the interface on the walker as simple as possible, and to utilise only on the visual interface if possible. However, the participants did recognise the fact that the visual system needed constant attention, and that having a non-visual reminder when a turn was imminent would be useful in the real world. To provide this reminder, the mechanical turning of the wheels was the prefered option. The audio interface was the only interface that was actively disliked by participants.

Figure 3.11: The research team that operated in Ciudad Real

3.1.8 Recommendations

A review of the visual interface by the researchers suggest that there are areas for improvement as follows:

- Improve the contrast between the text and the background.
- Make the change from a static arrow, showing general direction and a flashing arrow (at the point of redirection) more obvious.
- Place the distance information before the direction, rather than after, so for instance In 30 meters turn right.
- Include a landmark reference to improve confidence in the turn
- Provide the ability to look at an overall map of where the user is going and where he is to help orientation.

3.2 Final User Evaluation in Trento

3.2.1 The method

The initial prototype evaluation was carried out in Spain and a subsequent evaluation was conducted in Trento, Italy to increase the number and diversity of participants. After receiving ethical approval for the study from Northumbria University (SUB004_Toth_080914), the study was organised at University of Trento, Italy.

3.2.2 Participants

13 Participants were recruited from friends and relatives of staff at the University of Trento. Two of these were caregivers (41 and 44 years) and 11 were elderly people (aged 65-90, mean = 80.1; F=8, M = 3). Seven of the older adults reported having mobility problems.

3.2.3 Material

We ussed a c-Wlaker with the same configurations as for the experimetns in Ciudad Real repoerted above.

3.2.4 Procedure

The procedure followed was identical in most respects to the study carried out in Spain. What follows is mostly duplicatd from the Spanish study but is reproduced here for convenience. Upon arrival, participants completed a consent form to ensure that the participant was willing to take part.

Before starting participants received an explanation of the procedure. They then moved to the start of one of four routes and were given one of the four modality conditions to test (visual-only, visual-audio, visual-haptic and visual-mechanical). Directions were then presented to the participant via the visual interface along with another modality according to the condition.

The display would count down the distance to the point of turn and at the point of turn would display a flashing arrow to indicate that the turn had been reached. Throughout the trial, participants were accompanied by the researcher who corrected them if they made mistakes.

After the first trial, participants completed a short evaluation of the modality and commenced a new route with a different modality (each route was the same length). Aside from visual-only, the other modalities were haptic, audio and mechanical. The haptic modality required users to wear wristbands which vibrated at the point of turn in the corresponding wrist to assist the user.

The audio modality required users to wear headphones which emitted a beeping sound in the appropriate ear when the user reached the point of turn.

The mechanical modality rotated the wheels thirty degrees in the direction of turn at the point of turn to assist the user. If the user pre-empted the turn, the motor was either slightly or not activated.

Participants were presented with the four conditions (balanced association between route and modality) in a balanced order. After the user had tried each modality, they sat down and completed an overall questionnaire and were provided with refreshments. Following this, all participants were debriefed.

3.2.5 Results

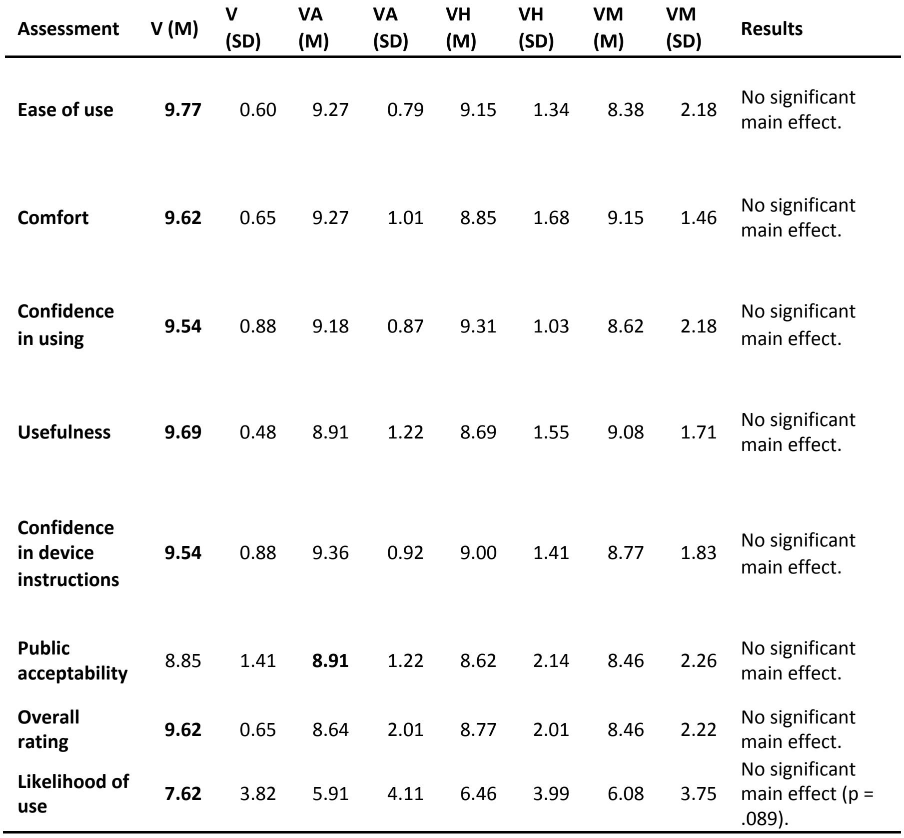
Participants were asked to rate the ease of use, comfort, confidence in using the interface, usefulness, confidence in the device's instructions, public acceptability, overall rating of the system and likelihood of using the system. Each was rated on a 10 point scale, where 10 was the best score. Repeated measures ANOVAs were conducted to see if there was an effect of modality on ratings. Four modalities were tested overall: Visual (V), Visual and Audio (VA), Visual and Haptic (VH), and Visual and Mechanical (VM). The findings are summarised below in Table 3.6. As can be seen from the results above, all the systems were rated very highly on all the measures until likelihood to use. Even though there were no significant main effects (although, likelihood of use came close), the visual system was consistently rated higher than the other modalities. While this was not the case in the public acceptability rating, it differed so little from the VA condition that it should not be considered notable. This suggests that the visual system, by itself, is preferred by the participants for a variety of reasons.

Paired samples t-tests were conducted to see if there were significant differences between ratings given to each modality. Significant differences and those close to significance are reported in Table 3.7

These significant and almost significant differences point to significantly higher ease of use of Visual (M=9.73) over VH (M=9.15) and VM (8.38), significantly higher comfort with visual (M=9.55) than VH (M = 8.85), significantly higher perceived usefulness of Visual (M = 9.69) than VH (M=8.69) and VA (M = 8.91), significantly higher overall liking for visual (M=9.62) than VM (M = 8.46) and significantly higher likelihood of use for visual (M = 7.62) over VM (M = 6.08).

All of this reiterates the consistent preference for the visual system rather than the visual system in combination with other systems.

Participants were also asked to state their prefered system. In this case 5/13 preferred the visual interface alone, 4/13 preferred the Visual and Haptic combined, and 4/13 preferred the visual and mechanical combined. This suggests that there was no system being preferred by the majority of participants and individual differences have a part to play.



Assessment	V (M)	V (SD)	VA (M)	VA (SD)	VH (M)	VH (SD)	VM (M)	VM (SD)	Results
Ease of use	**9.77**	0.60	9.27	0.79	9.15	1.34	8.38	2.18	No significant main effect.
Comfort	**9.62**	0.65	9.27	1.01	8.85	1.68	9.15	1.46	No significant main effect.
Confidence in using	**9.54**	0.88	9.18	0.87	9.31	1.03	8.62	2.18	No significant main effect.
Usefulness	**9.69**	0.48	8.91	1.22	8.69	1.55	9.08	1.71	No significant main effect.
Confidence in device instructions	**9.54**	0.88	9.36	0.92	9.00	1.41	8.77	1.83	No significant main effect.
Public acceptability	8.85	1.41	**8.91**	1.22	8.62	2.14	8.46	2.26	No significant main effect.
Overall rating	**9.62**	0.65	8.64	2.01	8.77	2.01	8.46	2.22	No significant main effect.
Likelihood of use	**7.62**	3.82	5.91	4.11	6.46	3.99	6.08	3.75	No significant main effect (p = .089).

Table 3.6: Descriptive Statistics and ANOVA results. The highest rated modality is in bold for each assessment

Data was also collected for the time taken for each route under each condition. A repeated-measures ANOVA was conducted to see if there was a main effect of condition on time taken to complete the routes. There was no significant main effect of modality on time taken to complete the routes. We combined the Spanish and Italian data to see if the increased sample size would produce more definitive results but again we found no significant effect. When we conducted paired samples t-tests on the Italian results, again we found no significant differences on time taken to complete the route based on the modality used.

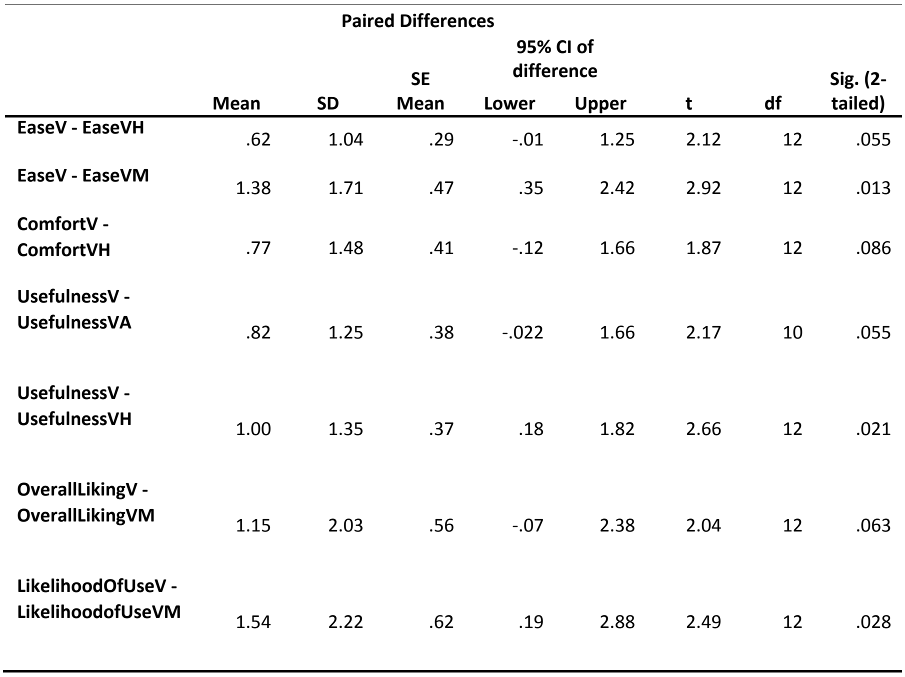
Comparisons of the mean times for each group (represented in Figure 3.12) show that the visual system by itself tends to result in faster times (or similar times) than the addition of any other modality. With the other modalities, participants waited for the signal as confirmation to the visual instruction, which may have made them slightly slower, but as shown adding this confirmation did not add significant time to the task. This means that in a real context, with more distractions from the visual interface, the addition of reminders in another modality, would potentially aid the navigation without significantly slowing a user.

3.2.6 Conclusions

Unlike the findings from the study in Ciudad Real, Spain, these findings do not show an overall preferrence for the visual system. Likewise, in terms of timing, users perform faster with the visual interface (or as fast) than with the addition of any other modality.

Users made several comments in support of this thesis:

"*I'm independent. I want to be free to decide. I prefer only the visual modality without any other redundant information*"



	Paired Differences							
				95% CI of difference				
	Mean	SD	SE Mean	Lower	Upper	t	df	Sig. (2-tailed)
EaseV - EaseVH	.62	1.04	.29	-.01	1.25	2.12	12	.055
EaseV - EaseVM	1.38	1.71	.47	.35	2.42	2.92	12	.013
ComfortV - ComfortVH	.77	1.48	.41	-.12	1.66	1.87	12	.086
UsefulnessV - UsefulnessVA	.82	1.25	.38	-.022	1.66	2.17	10	.055
UsefulnessV - UsefulnessVH	1.00	1.35	.37	.18	1.82	2.66	12	.021
OverallLikingV - OverallLikingVM	1.15	2.03	.56	-.07	2.38	2.04	12	.063
LikelihoodOfUseV - LikelihoodofUseVM	1.54	2.22	.62	.19	2.88	2.49	12	.028

Table 3.7: Significant (and almost significant) results of paired samples t-tests.

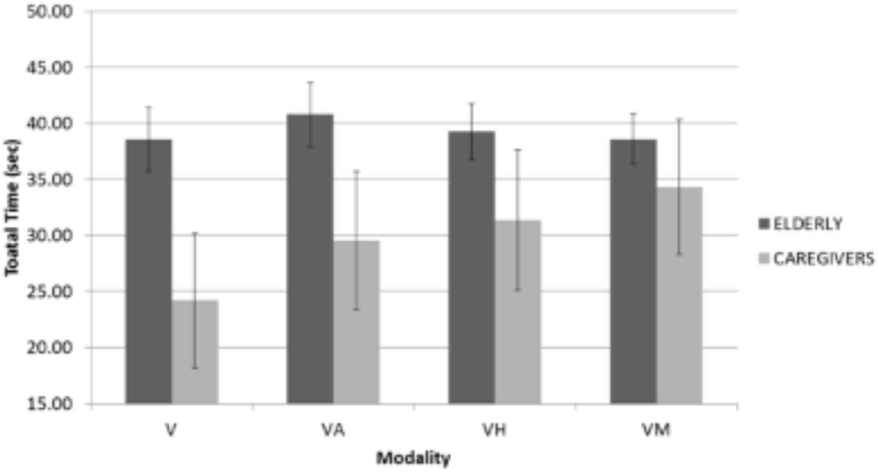


Figure 3.12: Graph of mean times and SDs for each modality

"*I can see well so I don't need anything more*"

Nevertheless, some users preferred the other modalities because they "*feel more guided*"(mechanical) or it "*frees all the other sensory modalities*" (mechanical).

Consequently, some caveats should be offered. Firstly, the speed of navigation is not always the most crucial factor. When older adults are navigating large and complex indoor spaces (unlike the smaller testing space), accuracy is likely to be more important than gaining a few seconds. Secondly, not all users prefer the visual system by itself and this suggests that individual differences play a role in determining the "best" system. Each user will have unique preferences. Thirdly, all of the users had reasonably good eyesight (i.e. no significant impairments). Had the sample included users with partial or complete blindness, their preferences would doubtless have been quite different. Fourthly, this evaluation allowed participants to fully concentrate on using the device, rather than the shopping experience, it may be that the other modalities, come into play, when there are more distractions, reminding the users to turn, when they are visually distracted.

3.2.7 Recommendations

We can say that, in general, a visual system alone is preferred by users and that the addition of other modalities does not generally improve performance in this context. However, we acknowledge that different users may have different needs and generalisations are not always helpful. The fact that some users prefer other modalities suggests that each of the modalities is useful, although only for specific users. We also acknowledge that other modalities will potentially contribute more benefit when there are more distractions in the environment.