Embodied Virtual Agents and Electronic Bracelet to support independent Travel by People with Cognitive Disabilities

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Abstract

Individuals with cognitive impairments have difficulties to independently use public transport. Some studies suggest that independence can be improved through effective orientation instructions and by reducing the travel anxiety. An Embodied Virtual Agent (EVA) as a travel assistant has the potential to provide valuable support. In this paper, we explore EVA capabilities, as a mean to improve the independence of individuals with cognitive disability, within a personal navigation application for mobile devices. We explore EVA ability to provide location-aware instructions that reassure users. Besides, we use an electronic bracelet (EB) equipped with an RFID-Reader to read mounted tags at the bus stop. The EB is able to effectively alarm the user for important EVA's instructions. Furthermore, it allows the user to check if a specific bus stop is correct in the context of the current trip and therefore helping in the decision making. Findings suggest that EVA and EB help to reassure and effectively perform the tasks inherent to a trip.

Introduction

Public transport plays an important role in promoting the social inclusion of people with cognitive disabilities, affecting their access to healthcare, work, education, social relationships and other basic services. The access to public transport is particularly crucial because many people of this vulnerable group typically are not able to use a car. There are, however, transport barriers that affect in different ways people with cognitive disabilities preventing them to independently use public transport. These barriers are for example related with their capacities to understand/remember transport information. The relevance of this topic has been stated most recently as a part of a European Parliament study (Lodovici & Torchio, 2015), which identify people with cognitive disabilities as a group with risk of social exclusion, and ultimately points to the lack of research in the area.

Research on assistive technology, identified needs and solutions for navigation systems that aim to support the bus usage by people with cognitive disabilities. Lemoncello et al. (2010) studied wayfinding performance of participants with

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cognitive disabilities and found that they perform navigational tasks with greater hesitancy and errors than non-disabled individuals. The authors concluded that assistive devices must provide concrete/explicit orientation instructions complemented with salient landmarks (Davies et al. 2010). They also recommended that navigational assistance must include the capacity to reassure the user in order to reduce his hesitancy/anxiety. Risser et al. (2012) identified several barriers that restrict the independent outdoor mobility, and concluded that the complexity of the environment, in combination with the lack of self-confidence results in uncertainty and fear to travel alone. Livingstone-Lee et al. (2014) examined 159 personal navigation applications (PNAs) and considered that only seven are suitable to assist people with cognitive disabilities. They recommended features for the future transit apps and highlighted that a PNA must be capable of reassuring users.

Smartphones offer a big potential to improve the navigational assistance (Livingstone-Lee et al. 2014). The tendency is that in future most of cognitive disabled persons will have experience in using smartphones. Furthermore developers have nowadays more freedom to create solutions because these devices offer a great computation and storage capability. This is an opportunity to explore the capabilities of an Embodied Virtual Agent (EVA) as a travel assistant that is capable to provide understandable instructions and reassure users. EVAs are virtual beings that interact with users through an expressive virtual body, capable of performing a natural verbal and non-verbal communication. A substantial body of work exists on the EVA functions. Prendinger et al. (2005) explored the emotional contagion effect and concluded that the presence of an empathic EVA can reduce the stress of solving a difficult task. Hone (2006) obtained a similar result maintaining that EVAs displaying sympathy or empathy can reduce the user’s frustration. Hone (2006) also concluded that a female EVA is more effective in the emotional influence than a male EVA. Additionally, EVAs are able to influence the motivation and enjoyment to use a technological system (Heerink, et al. 2008). Factors that impact this motivational ability are the social presence, the EVA capacity to smile, express emotions and to display a social behaviour in the technical system (Morandell, et al. 2008; Bickmore, et al. 2009; Heerink, et al. 2010). A very important and unique capacity of the EVA is the non-verbal communication. Body gestures, gaze behaviour, facial and emotional expressions provide extra information to the user. This capacity may (1) affect the decision making (Melo, 2010); (2) enhance the communication, by overriding verbal communication (Krahmer & Swerts, 2007); and (3) maximize the memorization (Buisine & Martin, 2007). These functions suggest that EVAs have the potential to support individuals with cognitive disabilities and help them to overcome barriers to transportation use. An EVA can help users in their travelling activities by employing easy language explanations or reminding the user an important task and ultimately to reassure them.

The EVA’s potential can be explored via smartphone. Nevertheless the alarming capacity of a smartphone can be insufficient e.g. vibration or beeping not perceived when smartphone is in a bag. Thus it’s important to complement the smartphone with a freehand mean that is able to effectively alarm the user for important EVA’s instructions. Currently available smart watches are undoubtedly a freehand device, capable to be synchronized with the smartphone, but far too complicated for users with mental disabilities. Additionally, the displays of these devices are difficult to read under strong sunlight. Therefore, it is considered necessary to build an EB from the scratch that integrates bright LED arrays to overcome the reading problems, a vibration unit to ensure an effective alarm and a Bluetooth LE unit for the communications with the smartphone. It is also considered important to integrate a RFID reader that allows a contactless identification of bus stops, because GPS based localization is not sufficient for example in subway stations. Furthermore GPS based systems often locate users on the wrong side of the street.

The purpose of the current study is to build a PNA and explore the Embodied Virtual Agent and electronic bracelet capacities to provide location-aware instructions that reassure users, and fundamentally help individuals with cognitive disability to independently use public transit.

Method

To investigate the effect of PNA on improving the independent use of public transport by people with cognitive impairments, a within-subjects design was chosen.

Participants

A sample of 7 adults was recruited to participate in this study (2 females and 5 males). Their average age was 31.14 years (*Range*= 24 to 48, *SD*= 8.35). All participants had light to medium mental retardation and epilepsy. Some participants were capable of reading at least words and had impaired speech capabilities. Some participants also present motoric problems. All participants provided written consent for participating in the study. It was made clear to the participants that all study data is confidential.

Materials

The study for testing of the PNA prototype in a real scenario rely on the insights/findings of previous explorations/analysis 1) observation study to identify the barriers in the mobility of the target group, and 2) employing participatory design methods to develop the PNA prototype.

Observation of barriers

Solving mobility problems means to get contact with environmental factors that might affect users. Accordingly, a qualitative field research study was conducted to determine and prioritize barriers in the mobility of individuals with cognitive disabilities. Ten subjects with different cognitive impairments did a leisure trip using public transport. Subjects were observed and the mobility obstacles, that prevented the participants to use public transport, were documented on the basis of the evolved observation sheet. A video-record from two different perspectives was also created for each participant (Figure 1). The data were analysed and the prioritization of the categories was determined by frequency count. The classification of the observed barriers ensued on foundation of the knowledge of Human Factors, who assumed that deviations in exogenous and endogenous factors might misconduct the independent using of public transport and be found at all levels of interaction between individuals and the complex system of public transport (Badke-Schaub, Hofinger & Lauche, 2012; Marquardt, Gades, Robelski & Höger, 2010; Wickens, Lee, Lui & Becker, 2004). Regarding the mobility barriers reasoned in cognitive processes the study indicated determining factors in the lack of temporal and spatial orientation, attention, and decision making. Furthermore, the outcomes show that barriers in the emotional sphere as anxiety, stress, insecurity, and lack of motivation are ponderous. Accordingly, there is a demand to reduce the uncertainty, to modify the decision making and motivation to use public transport.

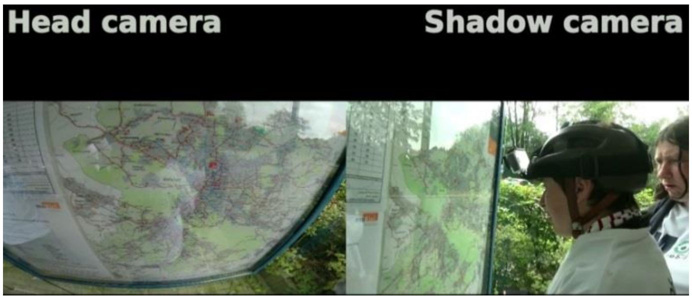

Figure 1. Videoed barriers observation.

Participatory design

In order to discuss the PNA´s mockup a focus group session with five subjects was conducted. The function of the PNA is to provide understandable instructions to users in the various moments of a trip. For the mock-up, it was defined a travelling story with a single bus route that was supported with street view panoramas. Mockup’s screens (Figure 2) were presented to the subjects on a laptop and discussed one by one.

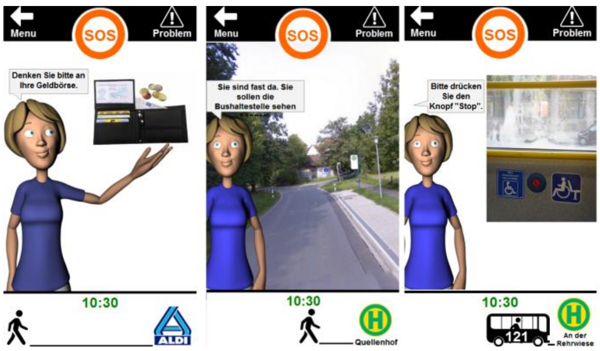

Figure 2. Mockup screens examples.

EVA’s messages were in general well understood; the misunderstanding situations occasionally happened because of some unknown words. This fact reinforces the importance of using an easy language. It was also concluded that every informative communication shall be succeeded by instruction from EVA. The contextual image that complements the EVA verbal communication effectively reinforced messages. Subjects also considered the landmark images a good support to the pedestrian navigation. In most of the cases the progress bar (based on concrete elements) was correctly interpreted, participants were able to understand the estimated time arrival and describe the progress bar. Additionally, it was found that the progressive construction of the user interface proved to be a good way to enhance the user interface understanding (Figure 3).

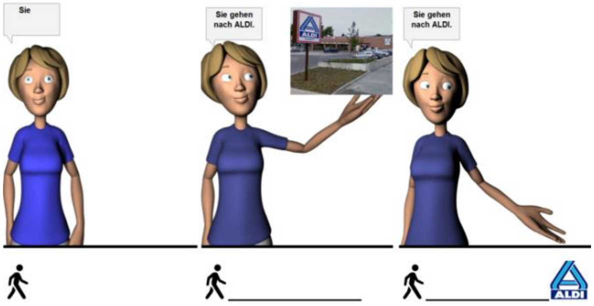

Figure 3. Progress bar construction.

In an exploratory session with 12 subjects, three focus groups were created to promote a discussion about the EVAs and the EB. With respect to the EVAs, it was found that subjects prefer a more visually realistic virtual agent. Participants understood correctly the facial expressions and realized how serious a message can be depending on the expression. Furthermore, subjects did not perceive difference between a perfect lip-sync and a simple lip-sync in which the speech audio starts synchronized with a random movement of the lips, and stops synchronized with the immobilization of lips. Some subjects considered the EVA's voice (text to speech based) unnatural. Finally, the nonverbal behaviour successfully enhanced the verbal communication with a bad audio quality. Regarding the EB, a green or red animation was used to inform the user that he is at the correct or wrong bus stop. This communication has been well understood by the subjects. The combination of a yellow animation and a vibration proved to be a reliable mean to alert user. Furthermore a LED bar and LED ring for displaying an amount of remaining time was shown to the subjects. However the usage of the same colour scheme for different purposes (e.g. red colour for wrong bus and less time) resulted in user confusion.

In a different session participants were invited to check a bus stop. This checking process consists of placing (1) the hand which wears the EB; or (2) the smartphone on a hand sign, resulting on the feedback: "correct bus stop" or "wrong bus stop" (Figure 4). The process was understood but the execution was difficult, because the EB or smartphone should be in contact with the surface, but subjects had no experience with that.

Figure 4. Left: Checking with electronic bracelet; Right: checking with smartphone.

Prototype System

The results obtained in the participatory design were considered for the construction of a functional prototype. This comprised two devices, the smartphone and the EB, and implemented implicit and explicit interaction. The implicit interaction was automatically triggered depending on the context. For instance, the instruction “press the stop button” was triggered near the destination bus stop (Figure 5). Implicit interaction always triggered the alert behaviour on the devices: yellow animation plus vibration on the EB, and an acoustic signal plus vibration on the smartphone. Explicit interaction was possible whenever the user places one of the devices on the hand sign installed in the bus stop (Figure 4), and by pressing the buttons on the smartphone screen (“hear instruction”, “repeat instruction” and “ok”). The devices were programmed to communicate via Bluetooth in order to trigger behaviours on the EB, for all events started on the smartphone and vice versa. The developed EVA was responsible for giving guidance. It was a female EVA with a human appearance able to perform verbal and non-verbal behaviours that were based on motion capture data. A female person was selected to record easy language messages to be used as the voice output of the EVA. Each message was recorded in two versions: 1) normal speed version; 2) slow version to be used whenever the user presses the repeat button.

Figure 5 . Starting from left: alert user; buttons to get the message; subject performing.

The prototype was able to provide support within a workflow: 1) identify the correct bus stop; 2) board the correct bus; 3) disembark at the correct bus stop. Accordingly, the prototype started in a pedestrian navigation context. When the bus stop was near, the EVA said “You are almost there” and the contextual picture of the correct bus stop was displayed. In the Bus stop area, the user was invited to check the bus stop. Then by placing the device on the hand sign the result was provided followed by an instruction (e.g. “wait for the bus”). The result of the check was reinforced by a colour scheme and non-verbal behaviour (e.g. stop gesture; Figure 6).

Figure 6. Starting from the left: EVA informing “correct stop”; EVA informing “wrong stop”; EVA instructing “correct bus stop is on the other side of the street”.

While waiting for the bus, the EVA informed the estimated time of arrival and a progress bar was displayed (Figure 7). When the bus arrived, a picture of the bus was displayed and the EVA instructed the user to board. Then just before the destination stop, the EVA instructed the user to press the stop button (Figure 5). When the bus arrived the user was instructed to disembark.

Figure 7. Progress bar.

In this study it was used a Wizard-of-Oz version for the implicit interaction (location/schedule based events). Over the course of the trip the Wizard constantly observed: (1) subject’s position; (2) time; and used a tablet computer to trigger behaviours via Bluetooth in the PNA.

Procedure

One month before the study a pre-test was conducted to verify the study method and train the participants to use the prototype. A well-known short route was chosen. Before the pre-test, the procedure was explained to the subjects. After, a HR monitor chest strap was presented and only installed by approval. The heart rate (HR) is one of the most simple and reliable stress and fear indicators (Hoyer et al, 2005; Wijsman, 2014). Finally the prototype usage was explained. The pre-test starts with a walk to the bus stop. In the bus stop area, the participants had checked the bus stop. Once the correct bus stop has been reached, the prototype instructed the participants to do a short drive by bus to a predefined bus stop. The pre-test has shown some procedure and usability problems such as missing the bus, long waiting times and not complying with the schedule. Hence some modifications were made for the study; for instance shortening the walk to bus stop and extending the bus trip. Furthermore, another training session was taken two days before the study.

For the evaluation it was selected a testing area where the participants were not familiar with the route. The duration of each evaluation session was approximately 25 min. The trip started with a walking part (2 min) to the bus stop area. There were two bus stops one on each side of the street (Figure 8). Buses came every 30 min and the waiting time for each participant ranged from 12 to 24 min. The bus trip took approximately 5 min.

Before the study each participant was equipped with an HR monitor chest strap. At the beginning of the study participant was briefed with the study procedure. The important travelling information like bus number or destination bus stop was provided. Then, a smartphone plus EB were handed and instructions on how to use the technology were given.

Figure 8. Origin bus stop area.

Each participant was accompanied by two researchers who lead the walking part until the bus stop area. Researchers just intervened to present the tasks and prevent dangerous situations. During the evaluation session, subjects were invited to solve four different tasks: (1) identify the wrong bus stop (before and after using the prototype) (Figure 9); (2) identify the correct bus stop (before and after using the prototype); (3) board the correct bus; (4) disembark in the correct bus stop, with the question "Is this the correct …?". After each task the question "How sure are you?" were asked. Sessions were videotaped with a chest mounted camera and the observer recorded the success vs. failure and the certainty level on a three-point scale (certain, partly certain, uncertain). Finally a post-questionnaire was conducted, comprising questions about the prototype acceptance and usability. The answers could be given on a three-point scale (agree, disagree, undecided).

Figure 9. Checking bus stop.

Results

SPSS was used to perform exploratory statistical analysis with the collected data to find out the significant differences in HR mean on the wrong and right bus stop before and after using the prototype. In the same way the frequency of the success and certainty was analysed in the four tasks. The HR mean was calculated for each task, using a 30 seconds sample, starting from the task presentation. To test the differences of the HR mean on the wrong and right bus stop before and after using the prototype, a 2 (bus stop) x 2 (pre and post measurement) within subjects and repeated measure ANOVA was run. The HR mean rises minimally at the right bus stop from 95.804 to 96.540. Regarding involving the effect of handling on the wrong vs. correct bus stop, the main effect was not significant (F (1) = .182; p = .688). However, there is a trend to significant contrasts effect (F (1) = 20.427; p = .006) before and after using the prototype. In comparison to HR mean before and after using the prototype the results shows that the HR mean decreases from 100.903 to 91.442.

Table 1 shows the cross-tabulation of success and certainty by task. Before checking the first bus stop with the prototype, three of the participants had success identifying the wrong bus stop, two participants failed and the other two participants did not answered. The well succeeded participants presented different levels of certainty and the two participants who failed affirmed to be sure. Furthermore, six participants succeeded in using the prototype and successfully accomplished the first task. One participant did not check the bus stop stating that the correct bus stop is on the other side of the street. From the six well succeeded participants, three affirmed to be sure and two present mid-level of certainty. Regarding the second task, before checking with the prototype, all the participants had success identifying the correct bus stop. Five participants affirmed to be sure and two showed mid-level of certainty. Furthermore, all the participants were able to use the prototype and successfully fulfilled the task. Due to a design limitation, the certainty level was not recorded after checking the correct bus stop with the prototype. In the third task all the participants identified the correct bus to board. Six participants were sure about their decision and one was unsure. Finally, all the participants disembarked the bus in the correct bus stop. In this last task six participants were sure and one participant shows mid-level of certainty.

Table 1. Cross-tabulation of success and certainty by task

	Identify wrong bus stop before using PNA	*Identify wrong bus stop after using PNA*	*Identify correct bus stop before using PNA*	*Identify correct bus stop after using PNA*	*Board correct bus*	*Disembark in the correct bus stop*
Success	3 (42.9%)	6 (85.7%)	7 (100.0%)	7 (100.0%)	7 (100.0%)	7 (100.0%)
Certainty	3 (42.9%)	3 (42.9%)	5 (71.4%)	-	6 (85.7%)	6 (85.7%)

Table 2 shows the frequency table of the acceptance questionnaire. The questions related with the performance expectancy and anxiety obtained a unanimous positive answer. Learning to use the PNA was considered difficult by one of the participants. Some participants reveal indecision or did not answer questions related with attitude toward using technology and facilitating conditions. Finally all participants considered it a good idea to use the PNA, and a majority showed intention to use the PNA in the future.

Table 2. Frequency table showing the acceptance questionnaire responses

	Agree	*Disagree*	*Undecided*
PNA is useful in my daily life	7	0	0
PNA enables me to accomplish a trip	7	0	0
PNA is easy to use	6	0	0
Learning to use the PNA is easy	6	1	0
Using the PNA is a good idea	7	0	0
PNA makes life more interesting	4	0	2
I like living with the PNA	4	0	1
I am able to use the PNA	5	0	2
I have enough knowledge to use the PNA	4	0	3
I feel apprehensive about using the PNA	0	7	0
It scares me to push the wrong button.	0	7	0
The PNA is intimidating to me	0	7	0
I want to use the PNA in the future	5	2	0

Table 3. Frequency table showing the usability questionnaire responses

	Agree	*Disagree*	*Undecided*
EVA helps me to accomplish a trip.	7	0	0
EB helps me to accomplish a trip.	7	0	0
Pictures on the screen were easy to understand.	7	0	0
I always knew which button to press.	5	0	2
It was easy to press the buttons.	7	0	0
I always understood the elements in the screen.	7	0	0
I always understood what the EVA said.	7	0	0
The EVA's voice was loud enough for me.	6	1	0
I found the EVA friendly.	7	0	0
The alarm (vibration and light) bothered me.	0	7	0
I know when the EVA has a message for me.	6	1	0

Table 3 shows the frequency table of the usability questionnaire. The EVA and EB were unanimously considered helpful. One participant considered that the volume level of the EVA voice must be increased. Other critical user interfaces were not considered problematic and the alarm event was well accepted.

Discussion

Findings suggest that the PNA’s prototype helps to improve the independence of individuals with cognitive disability, particularly to reassure and effectively perform the tasks inherent to a trip. In fact there is trend to significant effect before and after using the prototype that suggests absence of stressors, such as fear, after checking a bus stop with the prototype. Hereupon, it is considered important, as future work, to conduct a study by employing both experimental and control groups in order to compare differences in the physiological parameters of fear. Furthermore, testing and evaluating physiological parameters of fear and subjective fear assignment before and after using the PNA can increase the reliability of evaluating the certainty parameter. Additionally, it is important to analyse other situations where participants feel unsure.

Results from the questionnaire suggest that users do not feel anxious while using PNA. They consider it a useful tool that enables them to accomplish a trip. Participants rate the use of the PNA and learning to operate the PNA as easy. Some participants state to have enough capacities to use PNA. Connecting these results with the free comments suggest that more training is mandatory. Training can influence the confidence and ability in using the PNA and increase the desire for prospectively using the PNA. Regarding the usability of the prototype, the results indicate an unambiguous positive appraisal of PNA with a few exceptions in 1) sound 2) alarm perception and 3) which button to press. The last two points can be achieved via training.

Generalization of the aforementioned findings is difficult. For example, the researchers’ presence certainly affected the subjects’ behaviour (e.g. subjects looking to the researchers expecting answers or help). The small size of the group is also an important limitation and a larger sample is mandatory for further tests. In fact the sample size was also affected by the withdrawal (due to illness) of some participants. Finally, further investigations should be carried out to relate stress level with the execution efficiency. Following this idea it would be interesting to integrate a stress sensor in the EB that could influence the EVA´s behaviour depending on the context and stress level. This research has practical value, and if validated it might enhance the quality of life of cognitively impaired people, and would facilitate mobility inclusion for this vulnerable group of public transport users (Sherman & Sherman, 2013).

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