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USER PROFILES FOR FACILITATING CONVERSATIONS WITH LOCKED-IN USERS

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Abstract

The loss of communication is one of the most profound disabilities a human being can experience, inhibiting social contact and complicating medical and personal care. Locked-in patients are paralyzed and unable to speak, but cognitively intact. Developments in biometric technology provide non-muscular channels of control and provide opportunities to restore some communication for people with little or no muscle movement. Although these biometric devices have been effective, the input rate is very slow for the requirements of interactive communication. Prediction techniques increase the speed of communication in assistive technology. However, the user's context (time of day, location, presence of conversational partners, user's interests, etc.) can be included to make the selection of desired phrases or utterances easier and faster. This research presents an approach to developing user profiles for locked-in users. The profiles can be used to enhance the speed and accuracy of conversation by reducing the selection space for conversational topics. An empirical study that simulates the application of user profiles demonstrates how they can be used to improve the speed and accuracy of conversation in severely disabled users relying on augmentative and assistive communication devices.

Keywords: Assistive technology, augmented communication, biometric interface

Introduction

One of the most profound disabilities a human being can experience is the loss of communication and the ability to control his or her environment. Paralysis and the inability to speak can be caused by a variety of conditions including stroke, Amyotrophic Lateral Sclerosis (ALS), cerebral palsy, Parkinson's disease, and head injury. Severe communication impairments (SCI) affect the quality of life of over two million people in the United States (ASHA 2002), hindering social interactions, rendering personal and medical care difficult, and limiting options for recreation, education, and profession. The most severe physical disability, *locked-in syndrome*, is complete paralysis coupled with the inability to speak. Half a million people worldwide are considered locked-in, essentially prisoners in their own bodies (NORD 2000). Even more people have severe motor disabilities that prevent the use of conventional assistive technology (AT) devices to aid communication.

Augmentative and assistive communication devices (AAC) facilitate communication for people with severe disabilities, but their effectiveness is limited by the ability of the user to operate an input device. Environmental control devices can significantly improve one's quality of life by providing access to television, radio, and comfort controls such as thermostats and fans; however, most input devices require small, but reliable, muscle movements. Developments in biometric technology, such as brain-computer interfaces (BCIs) or direct brain interfaces (DBIs) and galvanic skin response (GSR) systems provide non-muscular channels of control and rekindle hope for restoring communication and environmental control for people with little or no muscle movement. Although these devices have been effective, the input rate, unfortunately, remains very slow for effective interactive communication and control. Communication strategies for people with severe motor disabilities are cumbersome, tedious for the conversational partner, and prone to error.

The objective of this research is to *develop a procedure for creating user profiles to increase the speed and accuracy of communication for people with severe motor disabilities*. To do so, a procedure for capturing, representing, and employing user profiles is developed and assessed by an empirical test. The long term contribution of this research is to significantly improve the ability of locked-in users to communicate by effectively utilizing user profiles to reduce the burden of communication.

Related Work

Prediction in Augmentative and Assistive Communication (AAC)

Augmentative and assistive devices seek to "increase, maintain, or improve the functional capabilities of individuals with disabilities" (Assistive Technology Act of 1998). They aid disabled users with various communication acts such as holding a conversation or composing a manuscript. Prediction techniques are being developed to speed communication in AT. These techniques focus on increasing the effectiveness of prediction and range from syntactic and semantic prediction (Darragh and Witten 1992) to conversational prediction (Alm et al. 1992), word recency, and triggers (Lesher 2001).

Prediction techniques have been successfully used in assistive communication to reduce the number of selections that an AAC user must perform by anticipating the next selection, usually providing a small group of alternatives, rather than the entire range of possibilities. Prediction methods can increase communication speeds by as much as 20 percent by taking into account word frequency, word recency and sentence grammar, and conversational patterns. However, the most dramatic increase in speed (400 percent) has been achieved by incorporating information about the user's environment or *context* (Cornish and Higginbotham 2000; Todman 2000). Aspects of the user's *context*, which includes time of day, location, presence of specific conversational partners, history of past conversations, and user's interests, could be combined to focus a communication system so that selection of desired phrases or utterances is easier and faster.

Prediction methods can increase communication speeds. These techniques attempt to reduce the number of selections that a user of an AAC system must perform by intelligently anticipating the next selection, usually providing a small group of alternatives, rather than the entire range of possibilities. For example, to find out where or how a locked-in patient is uncomfortable, simply identifying the part of the body needing attention is helpful. However, prediction does not normally reflect the user's context, which includes time of day, location, information about conversational partners, history of past conversations, and user's interests. Many of these aspects could be captured through user profiling, which could help make the selection of phrases or utterances easier and faster.

Thus, the successful engineering of contextual information into an AAC device can greatly enhance conversational prediction and increase a severely disabled user's control over his or her complex world. Prediction can also be used to streamline environmental control by providing only context-appropriate options to the user. Current approaches to prediction incorporate static (preset) contextual information; however, users, environments, and conversations are constantly changing and evolving. Thus, a strategy for incorporating dynamic information about context is needed to further improve communication.

Biometric Input Devices

Traditional methods of interacting with computers (keyboard, mouse, joystick, switches, and eye-gaze devices) depend on reliable and repeatable muscle movements. Figure 1 illustrates the continuum of input devices that may be employed when taking the user's abilities into consideration.

Biometric input devices directly measure aspects of human physiology, enabling people with little or no muscle control to operate computers and other devices. Direct brain Interfaces employ signals recorded from scalp or implanted electrodes allowing an individual to control a computer by detecting minute changes in brain signals (Wolpaw et al. 2002). Galvanic skin response, which has been used in psychotherapy (Cooperstein 1998) is being tested for its control potential (Randolph et al. 2005). Other biometric possibilities include functional near infrared (FNIR) (Stefanucci 2002) and magnetic resonance imaging (MRI) (Hornak 2003). Although these devices offer significant hope to people with no other options, they are very slow and cumbersome and have a high potential for errors. For example, the best performance for spelling with a DBI is 24 bits (i.e., three characters) per minute (Wolpaw et al. 2002). Thus, to optimize biometric device performance, methods are needed that reduce the number of interactions required to accomplish key tasks. Adding acceleration methods such as prediction to applications designed for biometric input devices may greatly enhance their utility.

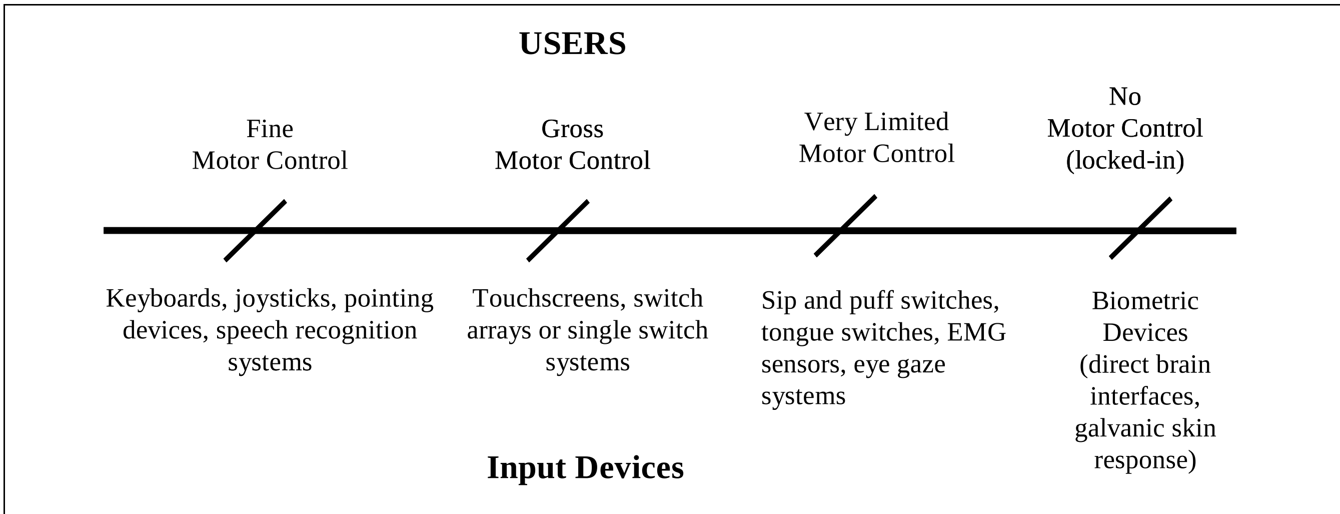

Figure 1. Continuum of Disabilities and Control Interfaces

User Profile Creation

This section presents a procedure for creating, representing, and using information to facilitate predication in conversation. There are two sources of knowledge: (1) "stocks" of publicly-available knowledge and (2) manually collected knowledge. These can be generally classified into the following knowledge forms and could be used to facilitate conversation: (1) real world knowledge databases, (2) domain ontologies, (3) conversational history, (4) user profiles, and (5) visitor profiles.

Real world knowledge: Real world knowledge refers to publicly available stocks of common knowledge such as the news of the day, including current events, politics, and sports as found on constantly updated Web sites such as CNN.com. Static stocks of knowledge such as maps or the restaurant domain, for example, can be found at local or specialized Web sites such as accessatlanta.com. Real-world knowledge includes an enormous variety of topics and domains.

Domain ontologies: An ontology is a way of describing one's world (Weber 2002). Ontologies have been proposed as an effective way to capture and represent contextual knowledge about the real world. The most effective way to capture knowledge specific to a problem is by *domain ontologies*. A domain ontology consists of the terms that occur in some application domain (e.g., auction, musical compositions, basketball) and the relationships among them (Gruber 1993). Since ontologies may be specified according to a particular domain, they are excellent candidates for representing information relevant to conversational topics of interest. The development of such domain ontologies is still a difficult process and one that is usually carried out manually (Embley 2004), although research is attempting to develop techniques to automate the ontology-creation process. Libraries of ontologies are beginning to emerge (e.g., **www.daml.org/ontologies**).

Conversational history: Conservational history captures interactions between a user and his or her conversational partner in order to provide a record of topics covered. This record, or history, can be used in a communication device to predict running threads of conversation. Records can be manual or recorded, but need to be analyzed for key words and phrases.

Individual user and visitor profiles: User profiles are a way of stating preferences and provide an inherent set of constraints. User profiles are typically knowledge-based or behavior-based (Middleton et al. 2004). Knowledge-based profiles reflect users' knowledge in the form of semantics; behavior-based profiles store records of users' actions. For locked-in users, behavior-based knowledge can only be extracted if prior history is available (e.g., before the user was locked-in or based on prior interaction with the user). Knowledge-based information must be extracted from records or interviews with family members and other close personnel. Profiles for both the user and visitors should contain, minimally, the following contextual information:

- personal (e.g., personal information, interests)
- temporal (e.g., temporally based activities, personal calendar)
- environmental (e.g., locations, artifacts)

- habitual or historical (e.g., current or past activities, historical record)
- relational (e.g., current relationships)
- medical (e.g., history and current status)

User profiles for prediction in augmentative communicative devices are intended to be most helpful in decreasing the amount of time it takes to select a topic for conversation by intelligently predicting conversational choices.

Unfortunately, there are no clear boundaries among the different knowledge forms. Common sense knowledge has problems of representation and scope. Ontologies have been very popular and generated a great deal of research interest. However, good methodologies do not exist for automatically generating ontologies. User profiles require either significant input from the user or effective techniques to automatically extract user profiles based upon prior activities of the user. This is difficult to accomplish with a locked-in user. Also, there can be overlap in these knowledge forms and it may not be clear which one to use. For example, the fact that baseball is played in a stadium could be common sense knowledge, knowledge that is stored in a domain ontology, or both. Then, the question remains about how to determine the user's preference in sports and whether to extract it from conversational history or what is stored in a user profile or infer it via some common sense reasoning mechanism.

For this research, first a domain ontology is created. Then, an individual user profile is created based upon conversational history, observations, and interviews. Common sense knowledge is not included in the current research.

Creation of the Domain Ontology

Approximately 40 percent of conversational time with a locked-in user is spent asking the user about his or her medical comfort and ensuring that the user's medical needs have been met (Adams et al. 2003). Thus, the first domain knowledge that we have tried to capture is for medical comfort.

Ontology for Medical Comfort

To create a medical comfort domain ontology of the medical domain knowledge, the detailed transcripts of conversations (conversational history) with locked-in patients were analyzed. The transcripts were recorded for visits to three locked-in patients by researchers, medical personnel, friends, and family. Recorded observations of visits by researchers and friends were also consulted.

The resources of domain knowledge were a taxonomy of body parts, conversational history summarized in Tables 1 and 2, and information from Web sites such as one published by the Association for Locked-in Syndrome. Table 1 shows the sources of transcripts and notes for generating medical comfort domain knowledge. Table 2 summarizes the visitors who were involved when the transcripts were recorded.

Extraction and Inferencing

To extract information regarding the comfort and care of locked-in patients, the terms and phrases were borrowed from various sources. For example, the Association for Locked-in Syndrome Web site (**http://www.club-internet.fr/alis/**) contains an article, "The Locked-In-Syndrome" by Philippe Van Eeckhout, that provides many details pertaining to the medical conditions of those suffering from locked-in syndrome. Van Eeckhout describes troubles with eye movement and the paralysis of side-to-side movement of the eyes. From this information, the phrase "I can't see" and others, is inferred.

Information for creating the medical comfort domain ontology was obtained by extracting key terms from the user profiles of locked-in patients. Figure 2 shows examples of extracting information from transcripts of user visits and inferencing key words and phrases to include in the medical comfort domain ontology.

For example, the singular term "windows" could easily have been extracted from the transcripts. However, one had to infer from the statement: "you been doin' windows lately," that the patient enjoyed facing windows based on information stated earlier in the transcripts: "How do you wanna lay? Towards the door?" which led to the addition of the phrase: "Face window," to the medical comfort ontology. General knowledge of the body was also used to add terms and phrases to the medical comfort ontology. For example, "hands" and "fingers" were found in the transcripts which led to the inference and addition of the term "fingernail."

Table 1. Sources of Transcripts and Notes for Generating Medical Comfort Domain Knowledge		
Patient	**Source**	**Visitor Type**
No. 1	5 taped conversations (4/17/2003-10/13/2003) Total time: approximately 300 minutes	Medical personnel, researcher, friend
No. 2	3 taped conversations (7/13/01-7/15-01) Total time: approximately 180 minutes	Researchers
No.1, No.2, No.3	5 sets of hardcopy notes of observations	Researchers, friends
No.1, No.2, No.3	5 sets of hardcopy notes of phone interviews	Medical personnel, family, friends

Table 2. Visitor Types During Transcription Process	
Patient	**Visitor Types**
No. 1	7 researchers, 3 friends as visitors, approximately 5 friends via telephone, 15 students from AT class, 1 family via telephone, 3 medical personnel (1 doctor, 2 nurses)
No. 2	3 researchers, 3 friends, 1 medical personnel (nurse)
No. 3	1 family

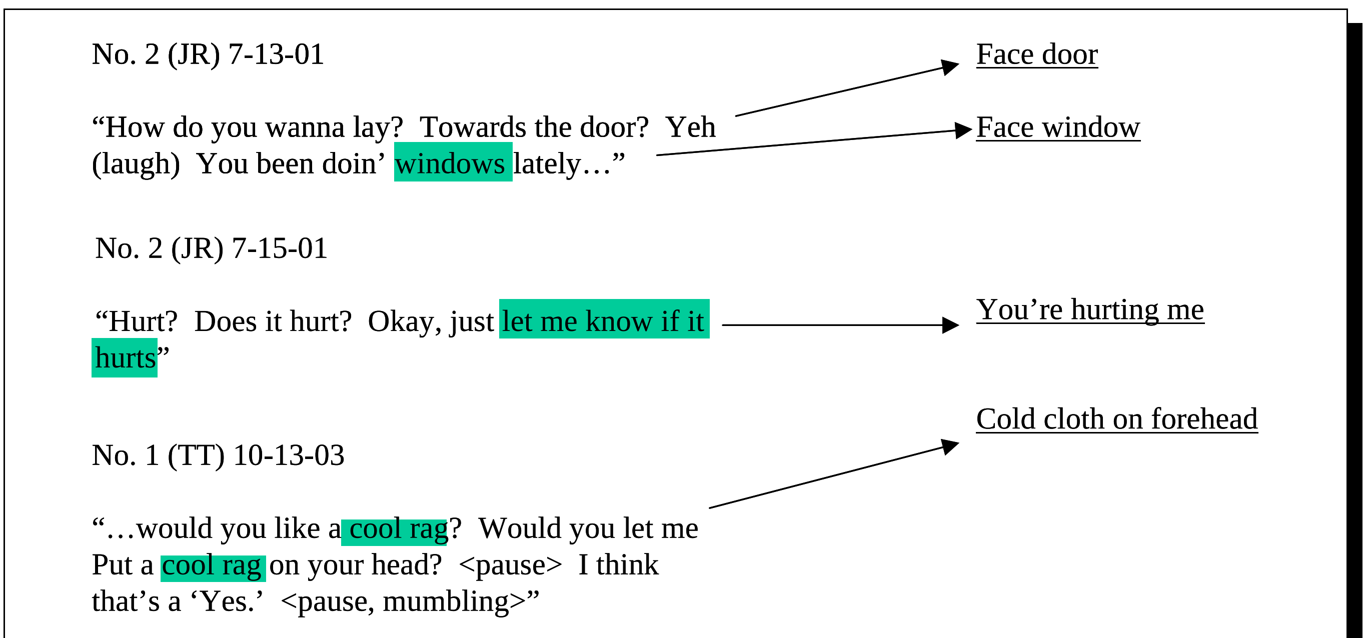

Figure 2. Extraction of Information for Medical Comfort Domain Ontology

Representation

After their extraction, the terms and phrases were organized into the medical comfort domain ontology for locked-in patients shown in Figure 3.

Creation of the User Profile

To create the user profile a procedure similar to the creation of the medical comfort domain ontology was used, focusing on the transcript analysis of one specific locked-in patient (Patient No. 1). Transcripts from five taped conversations and hardcopy notes of observations and phone interviews were used; these represented a variety of visitors consisting of medical personnel, researchers, family members, and friends. Table 4 summarizes these sources of information for the creation of the medical comfort domain user profile.

Figure 4 demonstrates examples of extracting information from a locked-in patient's transcripts of visits and inferring key phrases to include in the user profile based on the medical comfort domain ontology.

Figure 4 gives two examples where the researcher inferred phrases and terms from the transcripts. For instance, the portion of the transcript that states: "Do you want your head in the middle? (Adjusts head on pillow)," was used to create the phrase: "Adjust head middle." An example of the length of time it can take a locked-in patient to communicate even his or her most basic needs is illustrated in the second example where much later in the conversation the visitor finally realizes that the patient's stomach tube had fallen out. Other aspects of the user profile for this patient (No.1) are shown in Table 5.

Figure 5 shows the user profile portion based on the medical comfort domain.

Validation

To assess the usefulness of incorporating and using user profiles to predict conversation, we conducted an empirical study which simulated communicating a need or want of a locked-in user with and without having the user's profile available. The testing domain chosen was medical comfort. Two prototype communication systems were developed: (1) the *full version* consisted of the full core vocabulary and phrases as represented in the medical comfort domain ontology, and (2) the *modified version* captured the current user profile of a locked-in user based upon his transcripts.

Methods

Ten able-bodied university students participated in the study. The two prototypes (the full version and the modified version) were implemented with a scanning interface where the selection mechanism proceeds at preset intervals. The "body parts" section of the domain was represented graphically with an abstract picture of a human form that was scanned in three sections: head, trunk, and legs. The options that were available for selection were highlighted at a set interval of three seconds. The space bar on a standard keyboard was used for selection input in order to emulate the "yes/no" response capabilities of a typical locked-in user.

Each participant was asked to complete a practice communication task with the full system in order to familiarize himself or herself with navigating through the interface and making selections. Each participant was then asked to complete three communication tasks with each prototype version. In order to eliminate any learning effects, the order of prototype versions used to complete each task was varied by participant.

Each task differed by level of difficulty. Task difficulty was assessed by calculating the number of screens, the number of selection options, and the number of menu levels the participant traversed to complete each task successfully. The required tasks were to communicate the following utterances with the system:

Task A: "I'm tired"
Task B: "Adjust head to the middle"
Task C: "Ears sore"

***Body Parts**	***Physical comfort**

Head
Hair
Ear
    Right
    Left
Eye
    Right
    Left
Nose
Mouth
Chin
Back of head
Forehead
Shoulder
    Right
    Left
Elbow
    Right
    Left
Arm
    Right
    Left
Hand
    Right
    Left
Fingers
    Right hand
    Left hand
Fingernails
    Right hand
    Left hand
Chest
Back
Stomach
Pelvis
Hips
    Right
    Left
Butt
Leg
    Right
    Left
Knee
    Right leg
    Left leg
Foot
    Right leg
    Left leg
Toes
    Right foot
    Left foot
Skin
	-Actions
	    Cold cloth on forehead
	    Change sheets
	    New pillow
	    Change clothes
	    Clean me
	    Clean bed
	    Clean padding
	    Put salve on ***Body Part**
	    Put salve on bedsores
	    Massage Me
	    Massage ***Body Part**
	    Need eye drops
	    Cover Me
	    Take off cover
	    Scratch ***Body Part**
	    Rub ***Body Part**
	    Straighten ***Body Part**
	
	-Temperature
	    I'm Hot
	    I'm Cold
	    ***Body Part** Hot
	    ***Body Part** Cold
	
	-Reposition
	    Lay me flat
	    Sit me up
	    Put me on
	        Right side
	        Left side
	    Adjust Pillow
	    Adjust Head
	        Back
	        Up
	        Down
	        Middle
	    Arms
	        Out (of cover)
	        In (cover)
	    Hands
	        Out (of cover)
	        In (cover)
	
	***Personal Comfort**
	Face door
	Face window
	Read to me
	I'm tired
	I need to rest
	I feel OK
	I can't see
	I can't hear
	Call ______

*Medical Personnel	*Sick/Illness/Condition
Doctor Nurse Respiratory therapist ***Medical/Comfort Items** -*Comfort* Pillow Under head Under legs Blanket Sheet Chili suckers Salve Lotion Cold cloth Eye drops -*Medical* Vent Feeding tube G-tube T-tube Pick-line Needle Medication Hospital bed Hospital gown Phlegm Secretions	Surgery Procedure Pneumonia Upset stomach Coughing Fever Chills Sweaty Allergies Urinary tract burning Circulation Bedsores Heart beating fast Stomach tube came out Need suction Problem with vent Problem with suction You’re hurting me ***Body Part** sore hurt spasm irritated is bruised ***Medical/Comfort Items** hurt

Figure 3. Medical comfort domain ontology for locked-in patients

Table 4. Sources for Creation of User Profile

Source	Visitor
5 taped conversations (4/17/2003-10/13/2003) Total time: approximately 300 minutes Hardcopy notes of observations and phone interviews	Medical personnel, researcher, friend, and family

No. 1 (TT) 4-17-03

Do you want your head in the middle? (Adjusts head on pillow). You don't look real comfortable.

→ Adjust head middle

No. 1 (TT) 7-08-03

You need suction? Yes. It is really hard to cough when you have a ventilator so they have to come in and suction it out….

→ Need suction

NURSE: (incredulously) He's asking?!

MM: Yes. Well, I asked him if he needed suction and he said, "Yes." Tim, do you need suction? Do you still want suction? Yes. He says, yes. (To patient) Yes, of course you're asking—of course you can ask. Also, darling, you have got something going on over here. Hmmm, well that's not good, your stomach tube came out. Did you know that, too? Mmhmm.

→ Stomach tube came out

Figure 4. Extraction or User Profile on Medical Comfort

Table 5. Sample User Profile for One Locked-In Patient

User Profile Properties	Values
Objective Personal Characteristics	Name = Todd Age = 40 Gender = male Profession = land surveyor
Level of Knowledge of Particular Topics	Motorcycling = expert Land surveying = expert
Level of Interest In Particular Topics	Pretty women = high Blond jokes = high Motorcycles = high Television = high Movies = high Politics = moderate Former job = low Current events = moderate Medical care = high Family = high
Perceptual Skills	Cognition = intact
Motor Skills and Limitations	Vision = limited; central Motor = almost complete loss of all voluntary physical movement; limited control over eye movement
Medical Considerations	Ventilator = yes Disease = genetic mitochondrial myopathy

Medical and Comfort User Profile Properties	
***Body Parts**	***Physical comfort**
Head	*-Actions*
Ear	Cold cloth on forehead
Elbow	Change sheets
Hand	New pillow
Fingers	Clean me
Foot	Need eye drops
	Rub ***Body Part**
***Medical Personnel**	Straighten ***Body Part**
Nurse	
	-Temperature
***Medical/Comfort Items**	I'm Hot
T-tube	***Body Part** Cold
Medication	
Secretions	*-Reposition*
	Lay me flat
***Sick/Illness/Condition**	Sit me up
Coughing	Adjust Head
Allergies	Up
Stomach tube came out	Middle
Need suction	Arms Out (of cover)
You're hurting me	Hands Out (of cover)
***Body Part** sore	
	***Personal Comfort**
***Medical/Comfort Items** hurt	I'm tired
	I feel OK
	I can't see

Figure 5. User Profile Based on Medical Comfort Domain for One Locked-In Patient

No. 1 (TT) 4-17-03

"You don't look real comfortable. Let's get you off that ear. Your ear looks so sore. His ears get so sore. He lies on them all day and then they get so sore"

Ear ***Body Part** sore

Figure 6. Extraction of "Ears Sore"

All tasks were representative of conversations with locked-in users as identified by analyzing the transcripts. Figure 6 illustrates the interaction required for a locked-in patient to express the medical need in Task C: "Ears sore"

For each task with each prototype the time for task completion was calculated, as well as information regarding errors. The errors generated were of two types: (1) *selection errors* where the participant simply made an incorrect selection which resulted in a "false positive" because a selection was in fact made (positive) but it was incorrect (false); and (2) *overscan errors* where the participant missed selecting the appropriate response and the options "scrolled by" the participant who had to wait for the next iteration which resulted in a "false negative" because no selection was made (negative) and this was not an intentional action (false). After each task was successfully completed with both versions, the participant was asked to fill out a short questionnaire evaluating the speed and ease of the system and to provide an overall assessment. After all the tasks were completed with both

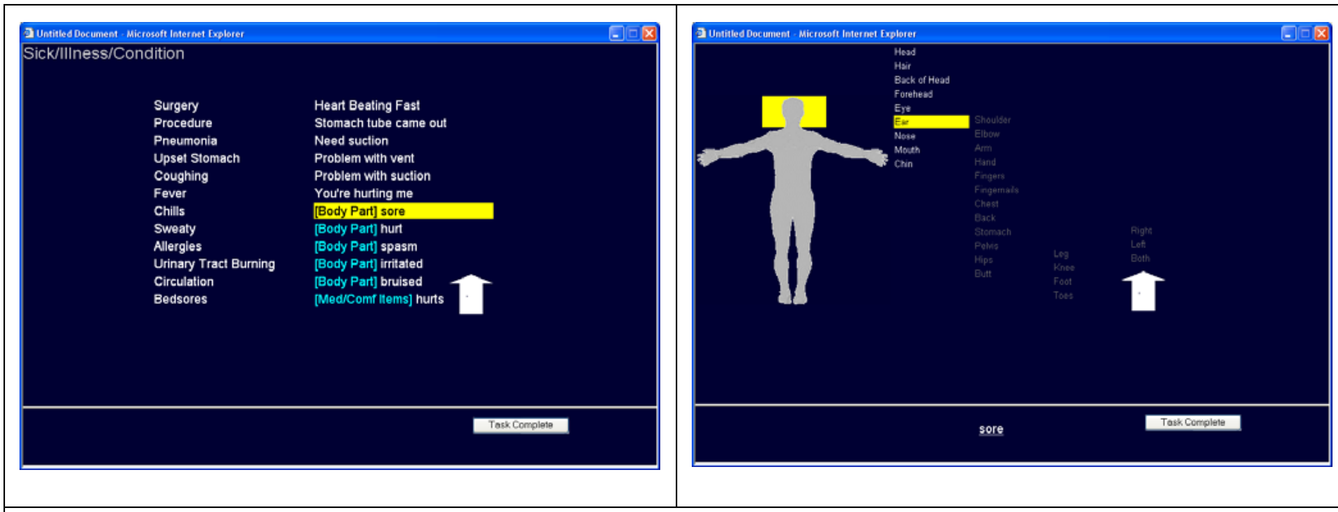

Figure 7. Full Version System Screen Shots for Task C

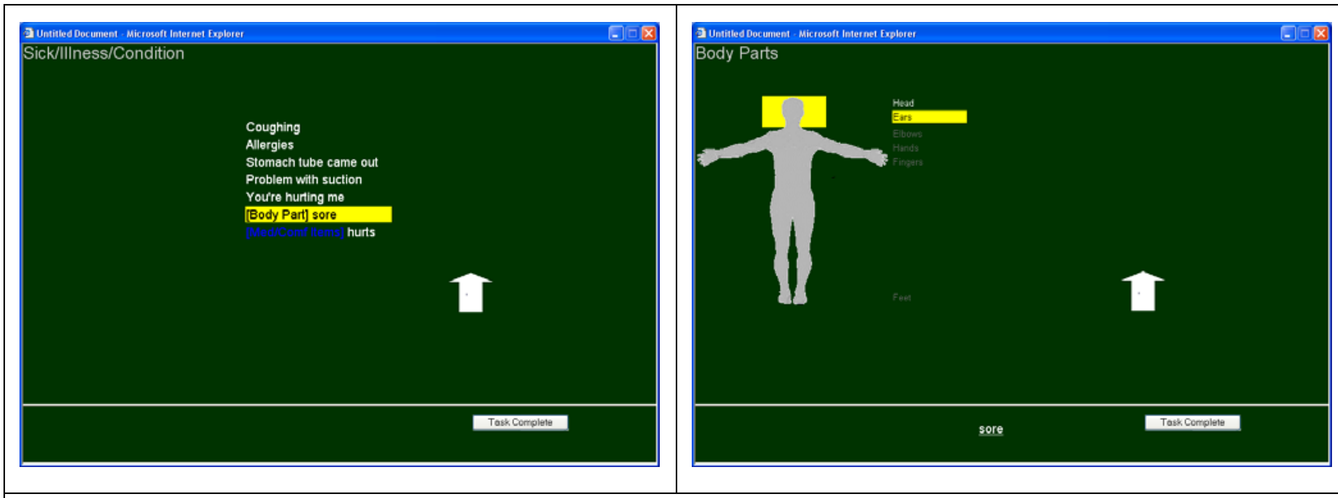

Table 8. Modified Version System Screen Shots for Task C

prototype versions, the participant was asked to fill out an even more comprehensive questionnaire evaluating both systems. (See the appendix for a copy of the final survey.)

Figure 7 shows screen shots of the full version (based on the domain ontology) for the completion of Task C: "Ears sore." Figure 8 consists of screen shots of the modified version (based on the user profile) for the completion of Task C: "Ears sore."

Analysis

The data obtained was analyzed based upon performance variables of human-computer interaction (HCI) measures (Higginbotham and Caves 2002). These measures are well-accepted in the field and have been shown to be effective for research related to users with AT. The most important of these HCI measures are

- *speed*—election and output rates (e.g., the length of time it takes to respond measured in seconds)
- *accuracy*—selection error rates measured in terms of the false positives and false negatives defined above

Descriptive analysis of any interaction problems was also incorporated.

Results

The completion time for Task A" "I'm tired" was 26 percent faster with the user profile version (modified according to the user profile) than with the full version (utilized the entire domain ontology). The completion time for Task B: "Adjust head to the middle"' was 20 percent faster with the user profile version than with the full version, and the completion time for Task C: "Ears sore"' was 60 percent faster with the user profile version than with the full version as shown in Table 6.

When participants were asked to rate the user profile version and the full version for perceived speed of system on a Likert scale of 1 to 9 (with 9 being the fastest), the user profile version was consistently rated higher across the tasks. The most noticeable difference in perception of speed can be seen for Task C as shown in Table 7.

Furthermore, when participants were asked to rate the user profile version and the full version for perceived speed of system on a Likert scale of 1 to 9 (with 9 being the fastest), the user profile version was consistently rated higher overall as shown in Table 8.

No selection errors occurred during the study. There were only two overscan errors (both occurred for tasks with the user profile version); this is attributed to the fact that, in both cases, the desired selection option was the first available option on the screen so if the participant was not familiar with the system it was easy to miss.

Conclusion

This research has attempted to show how identifying and using user profiles for locked-in patients using AAC devices can be used to increase prediction in conversation. To test the feasibility of incorporating user profile information for a locked-in patient, a domain ontology for the medical comfort domain was first generated. A user profile for one locked-in patient was derived from interaction with the patient, conversational history, and interviews. An empirical study was carried out to assess the speed of communication and perceived ease of use of a communication system integrated with the user profile. The initial results of the testing show that user profiles can be applied against a domain ontology for producing a reduced selection space for communication. This reduced selection space is advantageous for use with low bandwidth input techniques, such as those associated with biometric interfaces, for incorporation with AAC devices to improve speed while maintaining accuracy.

Table 6. Completion Time Increase of User Profile Version Versus Full Version

	Task A	**Task B**	**Task C**
Completion time increase	26.14%	19.88%	60.33%

Table 7. Perception of Speed of Modified Version and Full Version by Task

	Task A		**Task B**		**Task C**	
	Full version	User profile version	Full version	User profile version	Full version	User Profile version
Average Score	6	7.4	6.5	7	4.7	7.3

Table 8. Perception of Speed of User Profile Version and Full Version Overall

	Full Version	**User Profile Version**
Average score	5.6	7.8

These results are encouraging but significant effort is involved in generating user profiles for locked-in users, as this study also illustrated. The process involves concentrated efforts to compile observations, conversational history from transcripts, and interviews with close associates. Furthermore, although not all domain ontologies will apply to all locked-in users, there are areas observed to be significant that are common across users, such as the medical domain ontology. Future research is needed to fine tune the inferencing process for generating user profiles, automate the creation of relevant domain ontologies for locked-in patients, incorporate common sense knowledge as a source of input, and develop visitor profiles.

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Appendix. Final Survey

Please rate the **GREEN** and **BLUE** systems.

GREEN SYSTEM

1. Overall assessment
   Frustrating Satisfying
   1 2 3 4 5 6 7 8 9

2. Success at using system
   Unsuccessful Successful
   1 2 3 4 5 6 7 8 9

3. Speed in making selections
   Slow Fast
   1 2 3 4 5 6 7 8 9

4. Ease in making selections
   Easy Difficult
   1 2 3 4 5 6 7 8 9

5. Communicative success
   Bad Good
   1 2 3 4 5 6 7 8 9

6. Number of options per screen
   Too few Too many
   1 2 3 4 5 6 7 8 9

7. Scanning Rate (rate at which selection options were highlighted for selection)
   Too slow Too fast
   1 2 3 4 5 6 7 8 9

BLUE SYSTEM

1. Overall assessment
   Frustrating Satisfying
   1 2 3 4 5 6 7 8 9

2. Success at using system
   Unsuccessful Successful
   1 2 3 4 5 6 7 8 9

3. Speed in making selections
   Slow Fast
   1 2 3 4 5 6 7 8 9

4. Ease in making selections
   Easy Difficult
   1 2 3 4 5 6 7 8 9

5. Communicative success
   Bad Good
   1 2 3 4 5 6 7 8 9

6. Number of options per screen
   Too few Too many
   1 2 3 4 5 6 7 8 9

7. Scanning Rate (rate at which selection options were highlighted for selection)
   Too slow Too fast
   1 2 3 4 5 6 7 8 9