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ORIGINAL ARTICLE

Anomaly Detection to Increase Commuter Safety for Individuals with Cognitive Impairments

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Abstract This study assesses the possibility of using handheld devices to increase commuter safety for adults with cognitive impairments. The system uses a commercial off-the-shelf PDA (Personal Digital Assistant) with built-in GPS (Global Positioning System), enabling individuals to respond to unexpected situations without staff intervention. This study was performed according to an ABAB reversal design, in which A represented the baseline and B represented intervention phases. The data show that participants' awareness of anomalies significantly increased in target response, thus improving trip safety during intervention phases. Practical and developmental implications of the findings are discussed.

Keywords Anomaly detection · Assistive technology · Cognitive impairments

With sufficient and appropriate support, many people with cognitive impairments are capable of participating in the world of work, which provides both financial support and the opportunity for social integration (community-based living, recreation and leisure pursuits, use of community services, and use of public transportation).

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However, with increased independence and integration comes greater risk. For example, some dementia patients may suffer from spatial disorientation at unfamiliar places, or forget intended destinations (Wu et al. 2006); people with traumatic brain injury (TBI) or intellectual and developmental disabilities may not be able to recall clues of routes they previously trained to learn (Dutton 2003; Sohlberg et al. 2007).

With repeated training and daily practice, such individuals usually do not become lost or disoriented. However, they occasionally do forget how to travel to and from work. For example, part-timers with fewer shifts have a greater chance of forgetting the routes. Places with many distractions, few orienting landmarks, or surroundings that look similar, may worsen the situation. To decrease risk for individuals with disabilities as they increase community participation and seek social inclusion, recent strategies focus on increased autonomous functioning (Carmien et al. 2005; Ma 2009).

Because individuals with cognitive impairments are frequently dependent on others for support across environments, these strategies and skills must directly help access such support. Staff supervision can increase commuter safety; however, it is time-consuming and expensive. Furthermore, protracted or indefinite staff supervision emphasizes the dependence of persons with cognitive impairments, minimizing the value of responses.

Literature has reported the efficacy of assistive-technology devices in training adults with cognitive impairments, increasing commuter safety and enriching sensory and kinesthetic input without imposing burdens on staff (Patterson et al. 2004; Carmien et al. 2005; Baus et al. 2007). In such devices, machine-generated instructions alerted users when navigating or commuting to minimize disorientation. However, the devices were bulky and difficult to carry, and relied on other systems in the commuter vehicles to operate, making the system complex. Recent technological advancements allowed small-form factors of handheld PDAs with built-in GPS. With in-house software, self-contained PDAs can become intelligent devices that enhance commuter safety.

Transportation errors can negatively affect both job training and individuals' achievements and perspectives. Automatic anomaly detection, providing mild stimuli from an inconspicuous device, could help the individual respond to circumstances without staff intervention. Such a possibility would significantly improve achievement, occupational perspectives, and level of autonomy. Moreover, it would be viable in terms of time and cost. This study aims to help individuals with cognitive impairments surmount unexpected situations en route, without staff intervention. Conducting field experiments in community-based settings, researchers developed a system for four individuals with cognitive impairments.

Method

This study proposes a system called RADTI (Real-time Anomaly Detection for Traveling Individuals). RADTI uses a commercial off-the-shelf PDA with built-in GPS (Ma 2009; Chang 2010). The handheld device detects deviation from commuting routines and alerts the user. The RADTI system compares current trajectories in real-time against norms (expected trajectory patterns) previously collected by learning personal transportation routines. Individuals can use RADTI to detect anomalies such as taking the wrong bus, missing a bus stop, or getting off at the wrong stop. Alert modes include vibration and ringing, configurable to preference.

Many individuals with cognitive impairments have difficulty using smart phones and PDAs as assistive devices because of complex and abstract user interfaces. The RADTI system, however, does not require specific training procedures. The user interface is straightforward and has only two soft buttons: "start" and "stop." The hardware buttons on the panel and four sides are also locked to prevent accidental touch. The participant must still pay attention to alerts in sound, vibration, or the combination of both.

Participants

Participating rehabilitation institutes recommended individuals with differing disabilities and in various age ranges. Individual participants were screened according to degree of cognitive impairment, ability to achieve daily living tasks, and severity of short-term memory loss. Priority was given to medium- and low-functioning patients as opposed to high-functioning and very-low- functioning ones. Assessment of individual capabilities also took into account the ability to operate the PDA and understand its feedback. Four volunteers participated.

Al, age 28, had TBI after a car accident. Now he has mild dementia. His rehabilitation has gone well and he has been able to hold a paid job as a janitor. Al has been looking for, but not yet found, a more demanding job with higher pay, such as kitchen assistant or gas station manager. Ben, age 27, has Intellectual and Developmental Disabilities (IDD) and mild difficulties in memorizing routine procedures in his workplace. He occasionally gets lost and must call for help by cellular phone. Craig, age 46, has schizophrenia which makes him unable to distinguish ambient from imagined sounds. Currently he is unemployed, although he would like to work. Doug, age 38, has severe dementia and is forgetful of routes or work procedures. He has been unemployed since a car accident some years ago. However, he works very hard in the occupational rehabilitation center toward future employment. The participants were receiving pre-training programs in community-based employment projects sponsored by Affirmative Action Initiatives, Labor Affairs Bureau, Taipei. The system is intended to assist them with job qualification for positions such as mail courier, janitor, or parking patroller.

All four participants experienced being lost. A few years ago, Doug accidentally took the wrong bus; unable to identify the usual stop, he disembarked at the final station. He did not use a cell phone, and therefore could not contact anyone familiar. It was very late and there were no further buses. Anxious, his family called the police late that night. He was only found the next morning.

Setting

Throughout 2008–2010, each participant was invited to independent sessions on weekdays. Each session was one trip for an individual returning home from community-based training on a weekday afternoon. The travel time of a trip ranged from 0.5 ~1.5 h, including transits for some. Public transportation was used throughout the experiments. The ETEN X800 was the handheld device for the RADTI system.

Experimental Conditions

The study was carried out according to an ABAB reversal design, where A represents the baseline and B represents intervention phases (Richards et al. 1999). A session consisted of a single trip from work to home. One session a day occurred within each study period. Interest focused on sessions in which anomalies occurred. These were successful if the participant was independently aware of the anomalies. If he was not, or became aware 10 min after the beginning of anomalies, the session was a failure. For security reasons, a session terminated 10 min after an anomaly emerged. Therefore, only one anomaly could be observed in a session. For 1 week before the study, job coaches trained participants to use public transportation.

Baseline Phases

In the baseline phase, no assistive technology was applied. Starting at the workplace entrance, participants walked to the bus stop and boarded the bus at will. In each session, a team of three shadowed the participant to maintain security, observe, and record any anomaly.

Intervention Phases

In this phase, each participant carried the RADTI system for every session. Beginning at the workplace entrance, participants walked to the bus stop and boarded the bus at will. For quality satellite reception, participants were reminded to sit at a window seat. The alert mode was configured to vibration with ringing (except Craig, who preferred vibration only). In each session, a team of three shadowed the participant to maintain security, observe, and record any anomaly.

Results

The baseline and intervention phases demonstrated frequency of awareness of anomalies. In the baseline phases this meant that the participant committed an "anomaly" during a session and was independently aware of it. Awareness of anomalies in the intervention phases meant that a participant committed an "anomaly" during a session, and was aware of it either independently or by the device alert. The awareness was confirmed by oral communication (such as "Oops, this is not the way," "Where am I?" or "There is an alert coming from my cell phone"). Inter-observer agreement was reached by two of the three-member shadow team to ensure measurement-protocol reliability.

During the first baseline phase (five sessions), Al was aware of two anomalies (40%) (Fig. 1). During the first intervention phase (five sessions), the number

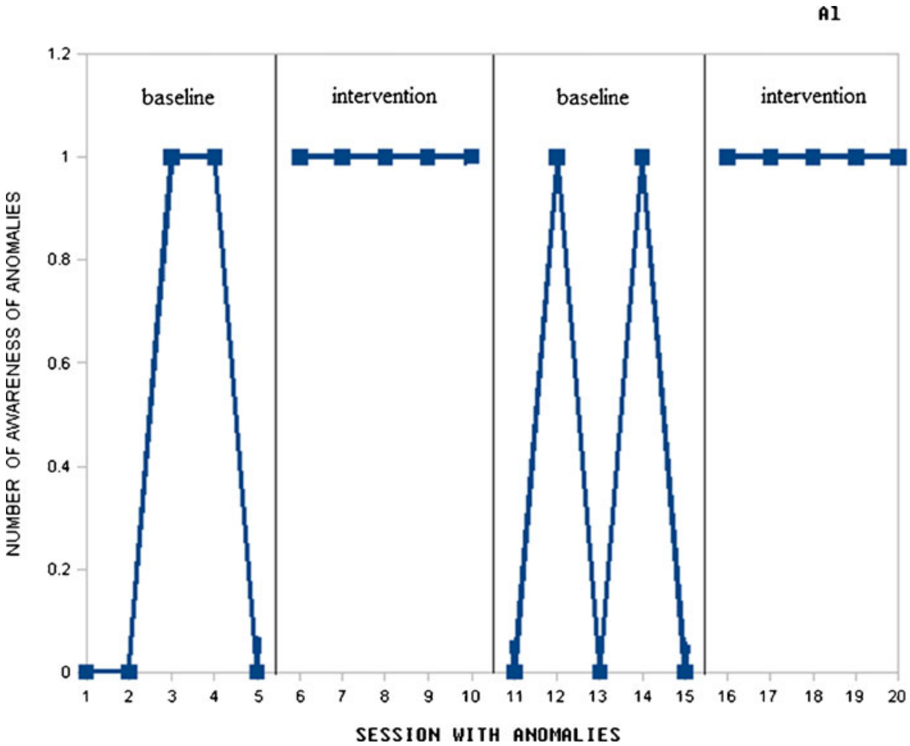

Fig. 1 Numbers of awareness of anomalies for Al

increased to five. His awareness of anomalies decreased during the second baseline (five sessions) with a total of two (40%) and rose again to five during the second intervention phase (five sessions). The difference between the baseline and the intervention was significant ($p<0.05$) on the Kolmogorov-Smirnov test (Siegel and Castellan 1988).

Ben's baseline and intervention phases provided data for awareness of anomalies (Fig. 2). During the first baseline phase (five sessions), the number of awareness of anomalies was three (60%). During the first intervention phase (five sessions), his awareness of anomalies increased to five. Awareness of anomalies decreased to three (60%) during the second baseline (five sessions) and rose to five during the second intervention phase (five sessions).The difference between baseline and intervention was significant ($p<0.05$) on the Kolmogorov-Smirnov test.

Craig's baseline and intervention phases also showed awareness of anomalies (Fig. 3). During the first baseline phase (five sessions), he was aware of two anomalies (40%). During the first intervention phase (five sessions), his awareness of anomalies increased to five. It decreased during the second baseline (five sessions) with a total of three (60%), rising to five during the second intervention phase (five sessions). The difference between baseline and intervention was significant ($p<0.05$).

Doug also demonstrated awareness of anomalies (Fig. 4). During his first baseline phase (five sessions), he was aware of one anomaly (20%). During the first intervention phase (five sessions), this increased to four (80%). His awareness of

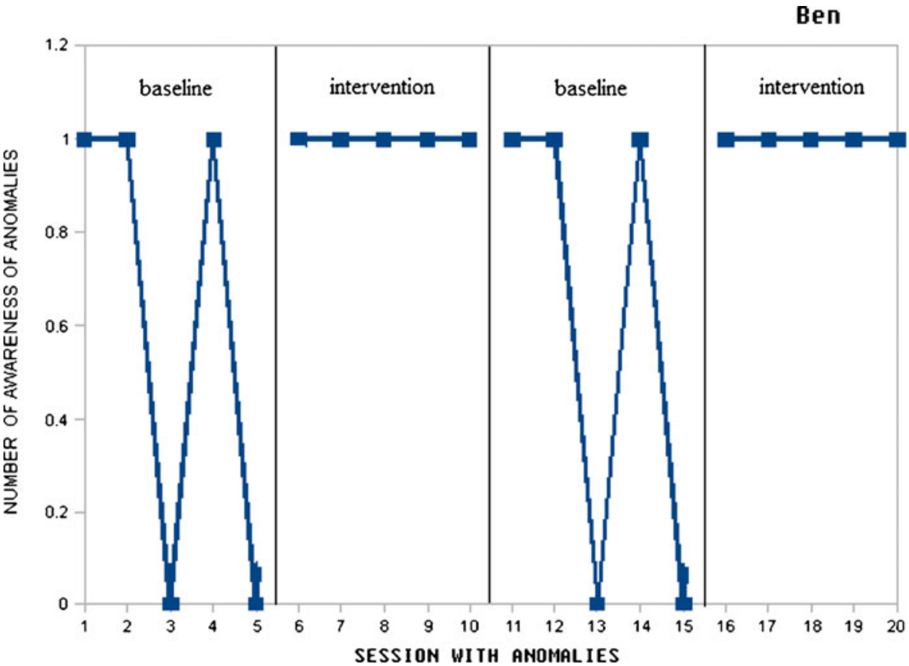

Fig. 2 Numbers of awareness of anomalies for Ben

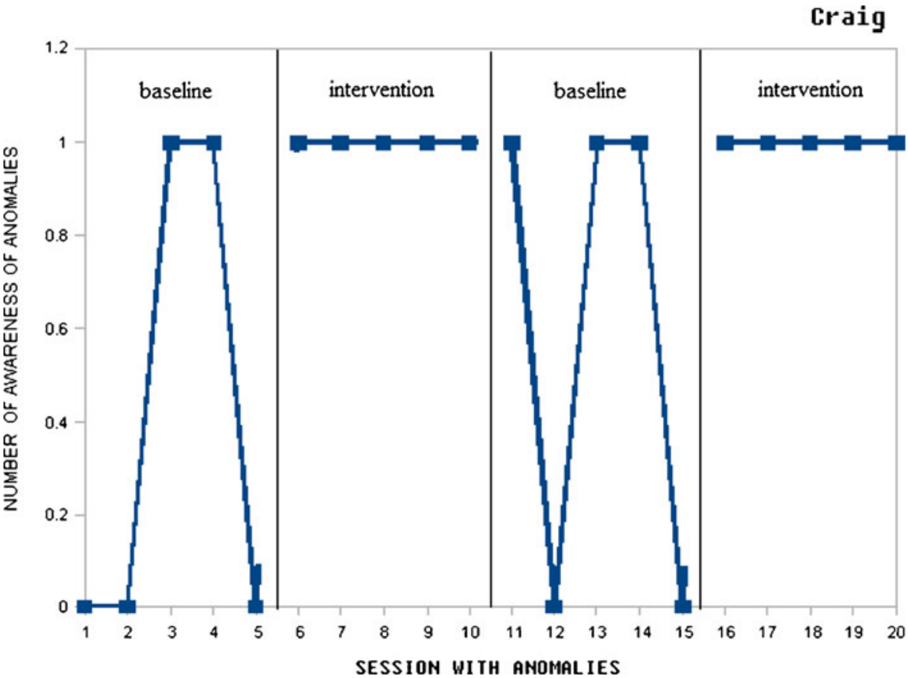

Fig. 3 Numbers of awareness of anomalies for Craig

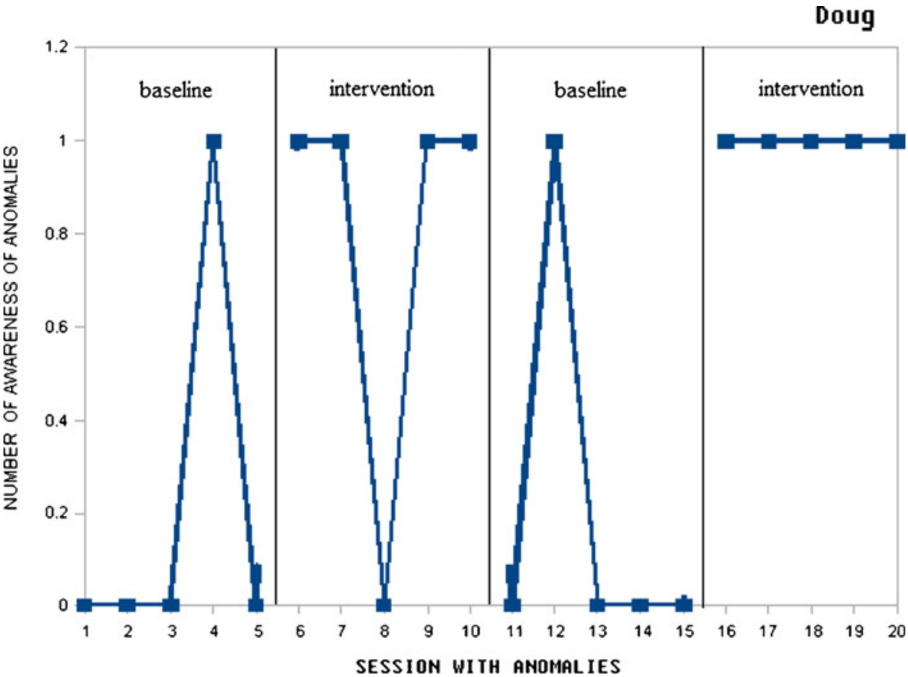

Fig. 4 Numbers of awareness of anomalies for Doug

anomalies decreased to one (20%) during the second baseline (five sessions), reaching five during the second intervention phase (five sessions). The difference between baseline and intervention was significant ($p<0.05$).

Discussion

This study assesses the RADTI system's effectiveness for detecting anomalies using a baseline/intervention experimental design. Doug missed the alert once during the first intervention phase, when the bus was crowded and noisy. Results for four adults with cognitive impairments indicate that the RADTI system in conjunction with operant conditioning strategies may increase safety in using public transportation. The participants' job coaches believed the device might improve their achievement, occupational perspectives, and level of autonomy while reducing risk of disorientation. Furthermore, it would be viable in terms of time and cost.

Results also suggest that RADTI in conjunction with operant conditioning techniques may enhance commuter safety skills for adults with cognitive impairments over operant conditioning techniques alone. Awareness of anomalies was greater during the intervention phase than the baseline.

This study focuses on anomaly detection. For security reasons, the shadow team terminated the session when a participant became aware of the anomaly or 10 min after the anomaly emerged, escorting the participant home in the latter case. The study does not consider other intervention measures, such as prompting the participants or providing corrective guidance. In case of anomaly, an errorrecovery procedure should be employed to go back or reschedule a new route. There are numerous of studies on navigation for the persons with disabilities, beyond the scope of this paper (Chang et al. 2009; Chang and Wang 2010b).

Social stigma was considered a potential issue before the experiment began. PDAs have existed for several years and people view them as they do cellular phones. Therefore, PDAs as assistive devices did not make participants a target of social stigma. Users exhibited low initial reservations and resistance about the device and the technology.

Ready-made or in-house specialized assistive devices provide additional accessibility, increasing, maintaining, or improving functional capabilities of persons who have physical or cognitive impairments and disabilities (Brodwin et al. 2004; Cook and Hussey 2002; Shein et al. 1992). However, such devices are often expensive and difficult to obtain or maintain compared to commercial off-the-shelf devices (Wessels et al. 2003). Commercial off-the-shelf products have many advantages, such as affordability, availability, good after-care service, good technical support, and low social stigma (Chang and Wang 2010a). Enhanced hardware or software assistive technology can repurpose many commercial high-technology products, turning them into high-performance assistive devices to match the special needs of persons with disabilities (Chang et al. 2010; Chang and Wang 2010b). However, researchers rarely propose this due to technological complexity. This study demonstrates that a commercial off-the-shelf PDA with built-in GPS, in connection with software enhancement technology, can be turned into a viable commuter aid. It improves the user's awareness of anomalies, and possesses the merits of an off-the-shelf product. This achievement enhances independence, status and quality of life for individuals with disabilities (Felce and Perry 1995; Wehmeyer and Schwartz 1998).

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