Web-Enabled Software for Clinical Telegaming Evaluation of Multisensory Integration and Response to Auditory and Visual Stimuli

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***Abstract*— Clinical telegaming integrates telecare and videogaming to enable a more convenient and enjoyable experience for patients when providers diagnose, monitor, and treat a variety of health problems via web-enabled telecommunications. In recent years, clinical telegaming systems have been applied to physical therapy and rehabilitation, evaluation of mental health, and prevention and management of obesity and diabetes. Parkinson's disease (PD) is suitable for development of new clinical telegaming applications because PD patients are known to experience motor symptoms that can be improved by physical therapy. Recent research suggests that sensory processing deficits may also play an important role in these motor impairments because successful motor function requires multisensory integration. In this paper, we describe a new web-enabled software system that uses clinical telegaming to evaluate and improve multisensory integration ability in users. This software has the potential to be used in diagnostic and therapeutic telegaming for PD patients.**

I. INTRODUCTION

Clinical telegaming systems are rapidly emerging as more convenient, comfortable and enjoyable alternatives to traditional approaches used in the diagnosis, management, and treatment of health problems. They enable delivery of telecare to patients in the comfort of their own homes instead of requiring these patients to travel to the clinic or hospital in order to receive care from providers. These systems combine the convenience of web-enabled telecommunications with the entertainment value of videogaming for a customized virtual environment intended to address the health care requirements of the patient. They have already been applied to therapy and rehabilitation for both physical health [1]–[4] and mental health [5]–[7]. Use of videogame therapy has demonstrated significant positive physical and psychological effects especially for older adults [8], [9]. Transforming health care interactions into a more enjoyable and convenient experience for patients, clinical telegaming systems are designed to motivate and encourage patients to participate more actively in maintaining and improving their own health.

Diagnosis and treatment of Parkinson's disease (PD) are ripe for new developments, and significant research has been done on therapies for PD. Much of this research, however, has remained focused on the motor symptoms of PD, such as exercises and therapy for posture, balance and gait [10]. Although PD has traditionally been characterized as a motor disorder [11], non-motor symptoms including those involving cognitive, emotional and sensory deficits have garnered considerable interest in recent years [12]. Non-motor symptoms represent a significant burden for PD patients, accounting for two of the top five most burdensome symptoms ranked by patients, both in early and advanced stages [13]. In addition, non-motor symptoms of PD are generally believed to emerge months or even years before onset of motor symptoms, providing a key target for early diagnosis of PD [12].

Clinical telegaming software that evaluates sensory processing deficits, such as our new prototype software named STEP (with an acronym derived from Sensory Training and Evaluation for Parkinson's disease), will have the potential to diagnose patients at much earlier stages of the disease, enabling the possibility of intervening with therapy to delay the onset of more burdensome symptoms [14]. Sensory processing deficits can be linked directly to motor symptoms. For example, diminished proprioception and vision are known to lead to difficulties in balance, gait, and posture, which are all common motor symptoms of PD [14]. Thus, clinical telegaming therapies that target sensory processing will not only facilitate earlier diagnosis of PD but will also have the potential to act as therapeutic tools for improving motor function.

STEP software (see Figure 1) specifically targets the process of multisensory integration in PD patients. Multisensory integration of visual and proprioceptive stimuli remains essential for planning and executing movement [15]. When multisensory cues conflict, multisensory integration must act to resolve those conflicts, often leading to the more dominant modality determining perception, or occasionally leading to multisensory illusions, such as the Double Flash Illusion [16], the Rubber Hand Illusion [17], and the Hand-Reversal Illusion [18]. Combining senses that reinforce each other enables confirmation of perception as well as resolution of possible ambiguities in perception [15]. Multisensory integration also acts to reinforce unisensory stimuli. It increases in healthy elderly subjects in order to compensate for unisensory losses [19]. In contrast, it decreases in PD patients. This deficit is believed to play an important role in the consequent motor symptoms of PD patients [20].

In this study, the ability of normal healthy subjects to perceive and combine multisensory stimuli has been evaluated both in cases of multisensory reinforcement and multisensory conflict. Although our goal for this study was to develop a basic prototype of a web application that could be used to test multisensory integration, we plan to develop a fully enhanced version of this software (as discussed further in the Conclusions) with an improved user interface design and elaborated game-like features for the user interaction

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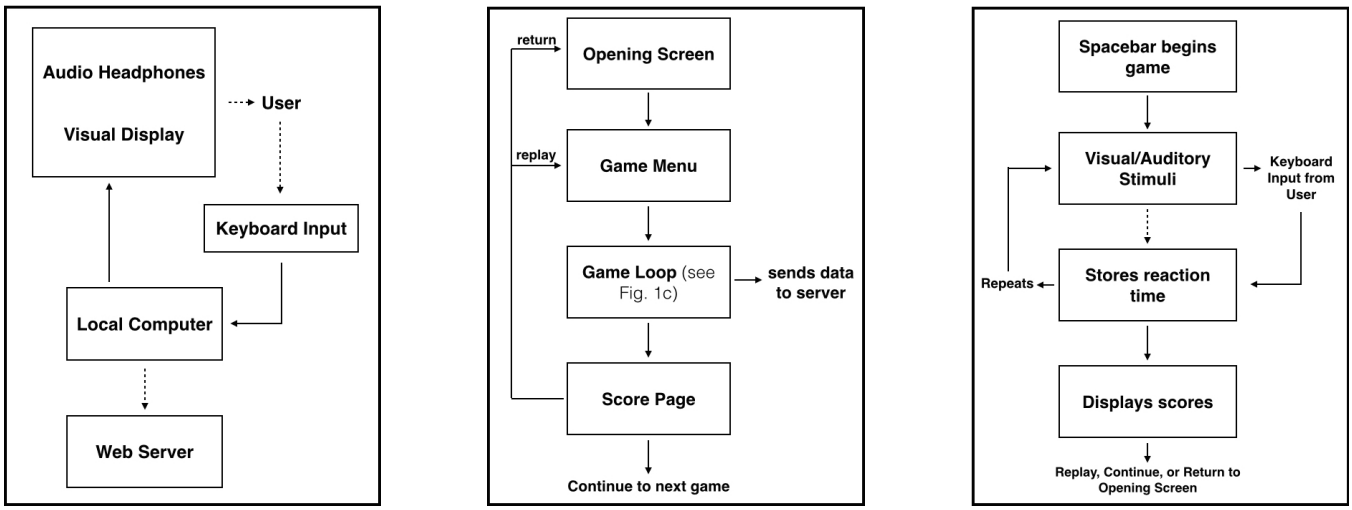


(a) System diagram (b) Software flowchart (c) Basic game loop

Fig. 1: Schematics for STEP software architecture.

with the software. This full version will be evaluated on patient subjects in order to determine the applicability of our software for the diagnosis and treatment of PD.

In the present study, however, only healthy controls were evaluated. We hypothesize for the evaluation of normal control subjects the following:

- Null hypothesis: Subjects will not experience any significant changes in reaction time and/or response accuracy in multisensory conditions when compared to unisensory conditions.
- Alternative hypothesis: Subjects will experience significant changes in reaction time and/or response accuracy in multisensory conditions when compared to unisensory conditions, with significant decreases in reaction time in multisensory reinforcement conditions and significant increases in reaction time in multisensory conflict conditions.

II. METHODS

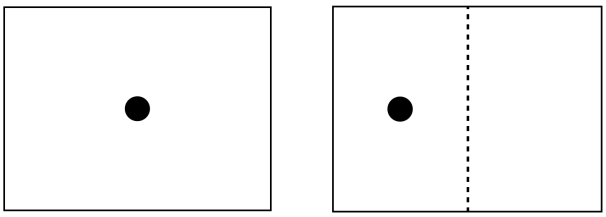
A. Procedure

STEP software evaluates multisensory integration ability by measuring response time and accuracy to visual and auditory stimuli. Subjects were tested on seven task variations, each testing a specific type of stimuli. Two of these conditions acted as controls for reaction time and presented an auditory or visual stimuli, given on both sides of the headphones or on the center of the screen (see Figure 2a). The user was instructed to respond by pressing the space bar as quickly as possible after perceiving the cue. Only response time was measured in the control conditions.

The five other test conditions each tested for a specific type of sensory stimulus condition including both unisensory and multisensory stimuli. Unisensory visual and auditory stimuli were presented on either the left or right side of the screen or headphones, respectively (see Figure 2b). Multisensory stimuli consisted of simultaneous visual and auditory stimuli presented on either the same side of the screen and headphones (reinforcement) or on opposite sides of the screen and headphones (conflict). The user was instructed to respond to visual and auditory stimuli by pressing the left and right arrow keys to indicate on which side the stimulus occurred. In cases of multisensory conflict, the user was asked to respond specifically to either the visual or the auditory stimulus. Both response time and accuracy were measured in the test conditions.

For each control condition, the user performed 10 trials, and for each test condition, the user performed 20 trials. Subjects were informed that both response time and accuracy were being measured for the test conditions. No immediate feedback on time or accuracy was given during the task, but after completion of each condition, reaction time and accuracy results were presented to the user before he or she continued to the next condition. The seven conditions tested are explained in more specific detail below:

1) Control Visual: A black circle as visual cue was flashed briefly at the center of the screen.
2) Control Auditory: A 50 ms 1 kHz tone as auditory cue was beeped through both sides of the headphones while the screen remained blank.
3) Unisensory Detection Visual (USV): A black circle as visual cue was flashed briefly on either the right or the left side of the screen.
4) Unisensory Detection Auditory (USA): A 50 ms 1 kHz tone as auditory cue was beeped on either the right or the left side of the headphones.
5) Multisensory Reinforcement (MSR): Visual and auditory cues were presented simultaneously on either the right or the left side of the screen and headphones with both cues occurring on the same side.
6) Multisensory Conflict Visual (MSCV): Visual and auditory cues were presented simultaneously on left or right sides of the screen and headphones with both



(a) (b)

Fig. 2: Computer display of visual stimuli. (a) Visual control condition: users were presented with a visual cue in the center of the screen and responded with the space bar. (b) Unisensory visual condition: users were presented with a visual cue on the left or right side of the screen and responded with the corresponding left or right arrow key.

cues randomly occurring on the same or opposite sides; response requested to visual cue.

7) Multisensory Conflict Auditory (MSCA): Visual and auditory cues were presented simultaneously on left or right sides of the screen and headphones with both cues randomly occurring on the same or opposite sides; response requested to auditory cue.

For the two control conditions #1–2, the subjects were instructed to press the spacebar as quickly as possible following the cue. For the five test conditions #3–7, the subjects were instructed to press the corresponding left or right arrow key as quickly as possible following the cue according to which of the two sides where the cue was perceived.

B. Software

Our web-enabled software STEP was run remotely by the user on his or her computer using a web client browser with either Google Chrome or Mozilla Firefox. Performance data was stored under an anonymous identification number for each user. Figure 1 displays schematics for the software architecture. Source code for the prototype version of the software and a video demonstration of its use can be downloaded from `www.BrainHealthAlliance.org/XLTSTEP`.

C. Participants

The software was tested with 11 normal subjects in three age groups: four young subjects (less than 25 years old), five middle-aged subjects (between 30 and 50 years old), and two elderly subjects (greater than 60 years old). All subjects were in good health (also known explicitly not to be suffering from PD) and gave informed consent to participate in the study.

III. RESULTS

Response accuracy was not significantly different across conditions for all age groups with subjects responding at greater than 90% accuracy in four of the five test conditions. The exception was the MSCA condition for which the average accuracy was somewhat lower at 83$\pm$6%. Reaction times summarized in Figure 3 are displayed with error bars representing standard error of the mean.

Figure 3a shows normalized measurements of the differences in reaction time between unisensory and multisensory conditions. Reaction times measured in unisensory conditions were used to normalize the reaction times measured for multisensory conditions, thereby accounting for individual variations in personal reaction time. For example, average reaction times for the MSCV condition were normalized for each subject by subtracting the subject's average reaction time for the USV condition from the subject's average reaction time for the MSCV condition.

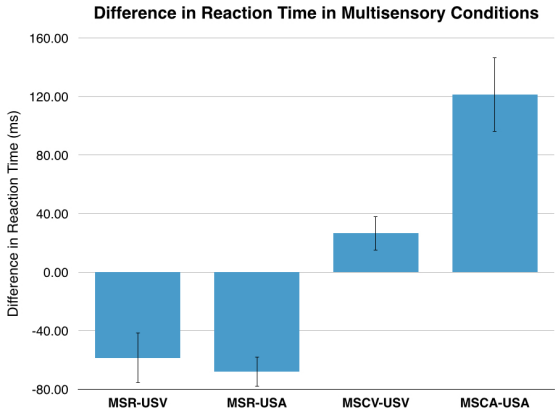
For the MSR condition, two normalized reaction times were calculated by subtracting the reaction times from USV in one case and from USA in the other case, thus addressing visual and auditory contributions to multisensory reinforcement. Reaction times for multisensory reinforcement conditions were faster than in unisensory conditions with a decrease of -58.5$\pm$34.1 ms and -68.0$\pm$20.5 ms relative to the USV and USA conditions, respectively. In contrast, reaction times for multisensory conflict conditions were slower than in unisensory conditions with an increase of +26.5$\pm$23.1 ms and +121.5$\pm$50.5 ms for the MSCV and MSCA conditions, respectively.

Figure 3b shows the normalized measurements of the differences in reaction time, separated by both condition and age. Members of the elderly subject group displayed considerably more improvement in reaction time in the MSR conditions when compared to other age groups. Elderly subjects also had considerably higher increases in reaction time in the MSCA condition but not the MSCV condition. However, this discrepancy from expected hypothesis may be an artefact of this age group's small sample size.

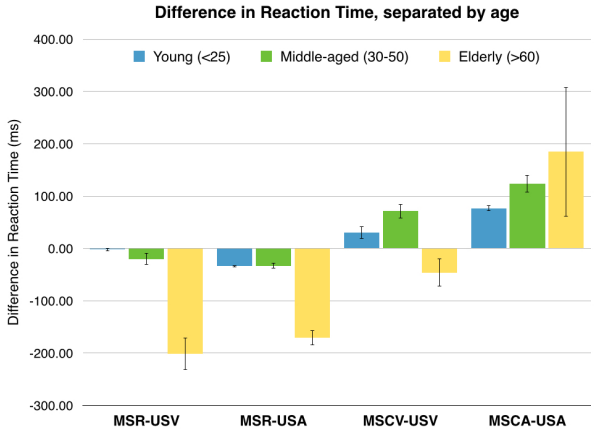
IV. CONCLUSIONS

In this study, we developed a prototype for a new web-enabled software system called STEP to evaluate users' abilities to perform multisensory perception and integration of auditory and visual stimuli assessed by reaction time and response accuracy measurements. We anticipate using this software to compare the performance of PD patients with normal healthy control subjects. As seen in Figure 3, normal subjects demonstrated considerable improvement in reaction time in multisensory reinforcement conditions. Normal subjects, especially in the elderly age group, demonstrated slower reaction times in multisensory conflict conditions with auditory stimuli. These results confirm our hypothesis and demonstrate the efficacy of this software in evaluating multisensory integration ability in healthy subjects.

We expect these differences will not be present in PD patients if these patients do experience an impaired multisensory integration ability as has been proposed in the literature. If PD patients are less able to combine different senses, we do not expect them to benefit from the presence of two simultaneous reinforcing stimuli. In addition, if PD patients are less dependent on their ability to combine multiple senses, and if they are overdependent on visual stimuli [21], we do not expect as great an increase in reaction time in the multisensory conflict conditions as observed for healthy



(a) Pooled age groups: When compared to unisensory condition reaction times, multisensory reinforcement decreased reaction times, while multisensory conflict increased reaction times.



(b) Separated age groups: Multisensory reinforcement conditions decreased reaction times by larger amounts in elderly subjects than in young and middle-aged subjects.

Fig. 3: Comparison of reaction time in unisensory and multisensory conditions.

subjects. Because these differences were more pronounced in elderly subjects (see Figure 3b), testing with a sufficiently large number of age-matched controls should reveal more definitive differences between the effects of multisensory reinforcement and multisensory conflict in healthy subjects and PD patients.

We are currently working to redesign our prototype for STEP with a new system architecture for both the server-side and client-side software. We plan to implement a secure web-enabled database and REST API for the web server while also refactoring the browser client software to meet standards and state-of-the-art patterns and practices for a live HIPAA-compliant secure system. We will then be able to conduct a clinical trial of our software with a much larger sample of both PD patients and healthy subjects to confirm and extend the preliminary findings of this study.

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