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Improving Target Acquisition for Computer Users With Athetosis

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Prior work has highlighted the challenges faced by people with athetosis when trying to acquire on-screen targets using a mouse or trackball. The difficulty of positioning the mouse cursor within a confined area has been identified as a challenging task. We have developed a target acquisition assistance algorithm that features transition assistance via directional gain variation based on target prediction, settling assistance via gain reduction in the vicinity of a predicted target, and expansion of the predicted target as the cursor approaches it. We evaluated the algorithm on improving target acquisition efficiency among seven participants with athetoid cerebral palsy. Our results showed that the algorithm significantly reduced the overall movement time by about 20%. Considering the target acquisition occurs countless times in the course of regular computer use, the accumulative effect of such improvements can be significant for improving the efficiency of computer interaction among people with athetosis.

Keywords: athetosis, cerebral palsy, computer access, target acquisition

Background

Athetosis is a complex movement disorder frequently found in cases of cerebral palsy (CP), as well as other diseases such as paroxysmal dyskinesia, thalamic stroke, and Huntington's disease (Blakeley & Jankovic, 2002). Athetotic involuntary motion lacks fixed amplitude, rhythmicity, or direction, and is highly irregular and difficult to predict (Koven & Lamm, 1954). It is typically described as a slow, wormlike, writhing motion, found especially in the upper limbs, and more pronounced in the distal musculature (Niku & Henderson, 1985). In addition to causing involuntary motion, athetosis also reduces the bandwidth of purposeful movements. The maximum frequency at which athetoid subjects can coherently track a moving target has been found to be approximately half that of control subjects (Neilson, 1974a). Likewise, the maximum velocity and acceleration is 30–50% of that of healthy subjects, and the lag in responding to visual stimuli is two to three times the typically value. To complicate the situation further, athetosis is often combined with other movement disorders such as spasticity (Penney & Young, 1998).

Persons with athetosis are often hindered in their use of computers, powered wheelchairs, and other assistive devices that commonly use manual inputs (Neilson, 1974a, 1974b). Personal computers have become ubiquitous and are being increasingly used by individuals of disabilities to communicate and participate in society. It is important to improve the performance of people with athetosis in computer use. One of the basic operations in computer use is target acquisition. With the popularization of computer applications using graphical user interfaces (GUI), users may constantly need to move the cursor to the desired location of the computer screen and make the selection.

Prior work has characterized cursor movements for target acquisition tasks among people with motor impairments. Hwang et al. investigated the cursor trajectories of six people with CP and three able-bodied users during a point and click task using a submovement analysis. Participants used a Logitech Wingman mouse (a force-feedback device) for input. The results showed that users with CP paused more often and for longer than able-bodied users and required up to five times more submovements to complete the same task (Hwang, Keates, Langdon, & Clarkson, 2004). Sibenaller investigated the cursor movements during target acquisition among 25 subjects with CP including 15 individuals with athetoid CP and 10 with spastic CP. Participants used a custom force sensing joystick for input. Dwell time of 2 seconds inside an icon was used to indicate selection of the icon. It was found that subjects could select the intended icon with a success rate of over 85%. However, the percentage of movement time before and after the first target entry showed that both groups spent over 60% of their time acquiring the target as compared to 40% of their time moving towards the target. Additionally, the number of target slip-offs after first target entry was found to be significantly higher for the athetoid group than the spastic group (Sibenaller, 2008). Trewin and Pain reported that 7 of 20 subjects with motor impairments rated pointing as being as hard or harder than any other mouse operation, 9 rated it as somewhat difficult, and only 4 rated it as easy (Trewin & Pain, 1999).

Techniques have sought to improve target acquisition performance, but many of them have not been evaluated among people with motor impairments, including those with athetosis. One

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technique is to slow down the cursor motion on and around the targets such as sticky icons. Hourcade et al. proposed PointAssist software that analyzes the characteristics for submovements, and detects when users have difficulty pointing, triggering a precision model that slows the speed of the cursor in those cases. The evaluation of PointAssist among 20 older adults showed that it had a statistically significant effect on click accuracy but not in movement time (Hourcade, Nguyen, Perry, & Denburg, 2010). An extension to the sticky icon is semantic pointing (Blanch, Guiard, & Beaudouin-Lafon, 2004), which adjusts target sizes in motor space without adjusting them visually to make them easier to acquire. This method was tested among able-bodied individuals and has shown to reduce the movement time by 10–15% for difficult tasks. Another technique is to expand the cursor or target in visual space to make it easier for target selection. Worden et al. examined the techniques of area cursor (i.e., enlarged cursor) and sticky icon among older adults and found that the two techniques, when combined, can decrease target selection times by as much as 50% when applied to the most difficult cases (i.e., smallest targets selection; Worden, Walker, Bharat, & Hudson, 1997). McGuffin and Balakrishnan tested the target expansion technique among 12 able-bodied adults and found that users benefited from target expansion even if the target only began expanding after 90% of the distance to the target has been travelled (McGuffin & Balakrishnan, 2005). Hwang et al. tested the target expansion technique among older adults and found that expansion can improve target acquisition times by up to 14% and reduce error rates by up to 50% (Hwang, Hollinworth, & Williams, 2013). Grossman et al. proposed a Bubble Cursor technique where the cursor dynamically resizes itself to remain as large as possible based on the locations of nearby targets (Grossman & Balakrishnan, 2005). They tested the Bubble Cursor with able-bodied individuals and showed that it significantly reduced target acquisition times in both simple and complex multi-target environments (Grossman & Balakrishnan, 2005). Murata conducted an empirical study to examine if the proposed target prediction algorithm can reduce the pointing time by testing able-bodied individuals, and found that the target acquisition time using the prediction method was less than that of the control condition (Murata, 1998).

Efforts to develop assistive computer interfaces for athetoid users have focused on using a single switch or alternative interface sites that may exhibit less athetosis than the arm and hand (Angelo, 1992; Lau & O'Leary, 1993). Work on developing and evaluating new techniques for improving target acquisition performance among people with motor impairments has been limited. Vazquez Lopez et al. designed a non-linear filter based on a cascade-correlation neural network model, and Olds et al. used an auto regressive stretching average method to filter the athetoid movement during target acquisition tasks. Both studies reported improvement in target acquisition time in offline experiments, but did not test the algorithms in real time (Olds, Sibenaller, Cooper, Ding, & Riviere, 2008; Vázquez López, Sibenaller, Ding, & Riviere, 2007). Wobbrock and Gajos tested the goal crossing method for target acquisition—where a user simply needs to move the cursor to cross a goal line—among 16 people, with 8 of them being individuals with motor impairments. They found that throughput for able-bodied users was higher for the traditional area pointing method than for the goal crossing method, but the opposite was true for users with motor impairments, suggesting that the goal crossing method may be viable for them (Wobbrock & Gajos, 2007). Trewin et al. developed Steady Clicks, a feature that helps suppress slipping errors while clicking and accidental clicks by freezing the cursor during mouse clicks, preventing overlapping button presses, and suppressing clicks made while moving at a high velocity. The feature was tested with 11 individuals who have motor impairments, and significant time savings were observed for five individuals (Trewin, Keates, & Moffatt, 2006).

As mentioned earlier, techniques such as sticky icons, target expansion, and target prediction have shown promise in reducing target acquisition time and improving clicking accuracy among able-bodied individuals and older adults. However, these techniques have not been tested in a combined manner and among people with athetosis. We have developed a method that integrated three assistance techniques, including transition assistance via directional gain variation based on target prediction during initial movement toward the target, settling assistance via gain reduction when in the vicinity of a predicted target, and expansion of the predicted target as the cursor approaches it. The method was evaluated using a closed-loop simulated athetosis model trained with movement data recorded from three subjects with different severity levels of athetosis (Rodriguez, Ding, & Riviere, 2010). Despite the fact that the method has resulted in a significant reduction in the target acquisition time based on the simulation result, the algorithm has not been fully tested among people with athetosis. The purpose of this study is to evaluate this algorithm on the efficiency of target selection by people with athetosis.

Methods

Participant Recruitment

Participants were recruited through use of Institutional Review Board-approved registries developed by the Human Engineering Research Laboratories and the Department of the Physical Medicine and Rehabilitation at the University of Pittsburgh. All subjects in the registries have provided informed consent to be contacted for future research studies. In addition, we also posted flyers in local rehabilitation facilities, outpatient facilities, and disability organizations. Subjects were included in the study if they were over the age of 18 and had a diagnosis of athetoid CP. They also had to undergo a screening test (described in the protocol section) to determine if they possessed the minimum motor skills and stamina needed for completing the study. Subject were not included in the study if they were unable to tolerate sitting for 3 hours, had active pelvic or thigh wounds, or had a history of seizures in the last 90 days.

Experimental Setup

This study used an isometric joystick as a computer pointing device. The isometric joystick was developed at the Human Engineering Research Laboratories as an alternative control method for power wheelchair driving and computer access for people with movement disorders. The isometric joystick was designed to be structurally similar to a conventional movement-sensing joystick with the voltage output being proportional to the force exerted on the handle. The rigid handle has a dampening effect that has been shown advantageous for people who have unintentional movements (Mahajan et al., 2011).

The experimental setup for this study consisted of an isometric joystick that was secured to a height adjustable table via a mounting bracket. The isometric joystick was connected to a laptop computer via a serial cable. The participants were asked to position themselves so that the isometric joystick was in the same position as their movement sensing joystick (Figure 1). The height adjustable table was used in order to best accommodate the participants when necessary. The laptop computer (Dell Latitude D505, with a display resolution of 1024 × 768) was placed at a comfortable distance away from the participants as they sat in their own wheelchairs. If the person did not use a wheelchair, they were given a chair with an arm rest to sit in during the study. Participants were also given an option to select from a variety of joystick handles that best match the joystick handle on his/her wheelchair.

Protocol

The protocol was approved by the Institutional Review Boards of the University of Pittsburgh and Carnegie Mellon University. The nature of the study was explained, and written informed consent was obtained from all participants before data collection. All participants underwent a brief upper limb neurological examination and were evaluated using the Modified Ashworth Scale (MAS) on the wrist and elbow joints of both upper limbs in flexion and extension. The MAS is considered the primary clinical measure of muscle spasticity in patients with neurological conditions. It adds a 1+ scoring category upon the original Ashworth Scale to indicate resistance through less than half of the movement, and thus is a six-point scale with scores ranging from 0 to 4, where lower scores represent normal muscle tone and higher score represent spasticity or increased resistance to passive movement (Bohannon & Smith, 1987). Information on demographics including age, gender, type of wheelchair used, and computer usage including computer independence, computer usage frequency, and type of pointing device used, were collected. The Barthel Index Score and Penn Spasm Frequency Scale were also obtained. The Barthel Index (BI) is a 10-item ordinal scale that measures functional independence in the domains of personal care and mobility. Scores range from 0 to 100, in steps of 5, with higher scores indicating greater independence (Collin et al., 1998). The Penn Spasm Frequency Scale is a self-report measure that assesses a person's perception of spasticity frequency and severity. It is comprised of two parts: spasm frequency and spasm severity. Scores for spasm frequency range from 0 to 4, with lower scores indicating less frequent spasticity, and scores for spasm severity range from 1 to 3, indicating mild, moderate, and severe spasticity, respectively (Priebe, Sherwood, Thornby, Kharas, & Markowski, 1996).

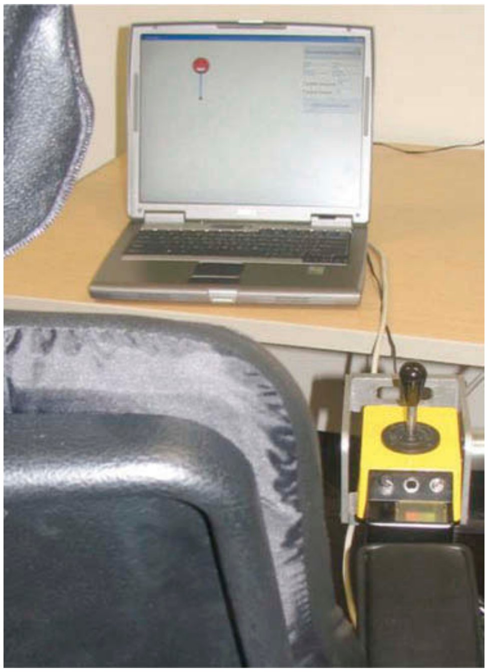

Fig. 1. Experimental setup.

The test session started with a 10-minute session where the participants practiced moving a cursor on a blank screen to become familiar with the isometric joystick. During this session, subjects were instructed by the investigators to move the cursor up, down, left, right, and towards the four corners of the computer screen. They then underwent a screening task where the participant was asked to move the cursor from the center of the computer screen to a circular target of 96-pixel diameter (approximately 1 inch) that was 192 pixels (approximately 2 inches) above the center using the isometric joystick. The target was considered to be successfully acquired when the cursor entered the target area and remained inside for at least one second, as indicated by a red smiley face. If the target had not been acquired within 20 seconds, the trial was automatically terminated and recorded as a failure, as indicated by a green frown face. At least 1 out of the 10 trials needed to be successfully completed in order for the participant to be eligible to participate in the study. These minimal criteria ensured that the participant was able to manipulate a joystick and produce movements, yet did not exclude participants who may not be able to control cursor movement.

After passing the screening task, each participant was asked to perform two sessions of target acquisition trials comprising a radial layout session and a random layout session. The two sessions represented different degrees of complexity and allowed us to evaluate our target acquisition method in both structured and unstructured conditions. Each session contained 60 trials including 30 assisted and 30 unassisted trials randomly presented. The assisted trial used the algorithm to modify the isometric joystick signals to assist participants to acquire the targets.

- In the radial layout session, the computer screen showed eight circular targets in grey, each with a diameter of 96 pixels (approximately 1 inch), arranged every 45 degrees along the radial directions of a circular pattern with a radius of 288 pixels (approximately 3 inches). Each trial began with the cursor set at the center of the circular pattern by the software. The investigator used a button on the screen to activate a new target by changing its color from grey to yellow. Participants were asked to acquire the yellow target and needed to dwell inside the target for at least 2 seconds to complete the trial successfully. A trial was recorded as a failure if the target had not been acquired within 20 seconds. One of the eight targets was randomly selected for each trial, and the selection was balanced between assisted trials and unassisted trials.

- In the random layout session, only two targets, each with a diameter of 96 pixels (approximately 1 inch), were shown on the screen in each trial. Subjects started with the target colored in blue, and were asked to acquire the other target when it changed the color from grey to yellow upon the click of a button on the screen by the investigator. They needed to dwell inside the target for at least 2 seconds to complete the trial successfully. A trial was recorded as a failure if the target had not been acquired within 20 seconds. After a trial was completed, the previous starting location disappeared and the acquired target then became blue, indicating it would be the start position for the next trial. The cursor was then set by the software at this position, and a new target in grey appeared on the screen. The target locations on the screen were randomly chosen, but the distances between the targets were preset at various values and balanced between assisted and unassisted trials. The distances ranged from 100 to 1000 pixels. The assisted and unassisted trials in each session were counterbalanced to reduce order effect. The session order was also randomized among the subjects. Rest was given in between sets of 10 trials when requested by the participants. The cursor positions, digital output signals from the isometric joystick, and the trial status (success or failure) were recorded using customized software.

The Algorithm

The algorithm that provided three types of assistance including the transition assistance, settling assistance, and target expansion was described in details in Rodriguez et al. (2010), and summarized as follows.

- Transition assistance: First, the intended target is predicted based on the time history of the cursor movement similar to the work by Murata (1998). The angle between the instantaneous movement vector and the instantaneous vector toward the center of an icon is computed for each icon on the screen at each time instance. The icon with the smallest integral (or running sum) of angle values is predicted to be the intended target. Next, in order to speed the cursor toward the intended target, a variable gain is implemented as a function of the direction toward the predicted target icon.
- Settling assistance: In order to reduce settling time, a reduced control-display gain is used when the cursor is in the vicinity of a predicted target. This is similar to “sticky icons,” except that in this case, the region of reduced gain extended beyond the icon, rather than being reduced only inside the icon.
- Target expansion: Based on the Fitts’s law (Fitts, 1954), it is reasonable to expect that enlarging the predicted target can decrease target acquisition time. We have incorporated linear enlargement to gradually expand the predicted target. The way in which the size of the predicted icon increases is determined by its original diameter, the distance between icons, and by two parameters specifying how much to increase the target size and the distance at which the size begins to increase. In this study, the target size was set to expand to twice the original size, and the expansion started gradually after 50% of the distance to the target had been travelled.

All the parameters used in the algorithm were empirically determined based on a closed-loop athetosis model trained using data collected from three subjects with varied levels of athetosis (Rodriguez et al., 2010).

Data Reduction

The overall MAS used in the data analysis was obtained by taking the median of the four MAS scores for the wrist and elbow joints in flexion and extension in the upper extremity that controlled the joystick. Cursor movement data were sampled at a rate of 100 Hz and down sampled to 20 Hz for post processing. Three measures based on the cursor movements were calculated: (1) success rate—the success rate was obtained for the assisted and unassisted trials in both test sessions (i.e., radial layout session and random layout session); (2) movement time—the movement time was also calculated for each trial and averaged over 30 assisted trials and 30 unassisted trials for both sessions; (3) distance ratio—the distance ratio was calculated as the ratio of the actual cursor trajectory length over the direct length to the target, and was calculated for each trial and averaged over 30 assisted trials and 30 unassisted trials for both sessions.

Statistical Analysis

Descriptive statistics including mean and standard deviations for continuous data and frequencies for categorical data were calculated for all variables. A two-way repeated measure ANOVA with the test session (radial vs. random layouts) and assistance provided (assisted vs. unassisted options) as independent variables was performed to examine the main effect of the assistive techniques on movement time and distance ratio under the two test sessions. All statistical analyses were completed using SPSS version 14.0 software. Statistical significance was set at 0.05.

Results

Five women and two men with athetoid CP participated in the study. The average age (mean ± standard deviation) was 47.0 ± 8.7 years old. All of them used a power wheelchair as their primary means of mobility. They were able to use a computer independently and reported to use a computer at least several times a week. Four of them used a trackball mouse to access a computer, and three used a traditional mouse. The median MAS was 2 with a range from 1 to 4. The mean BI was 60.0 ± 26.3. The median spasticity frequency and severity based on the Penn Spasm Frequency Scale was 2 with a range from 0 to 4, and 1 with a range from 1 to 3, respectively.

Tables 1 and 2 describe the results including the success rate, movement time, and distance ratio averaged over 30 trials for each subject in the radial and random layout sessions. During the radial layout session, the average success rate, movement

Table 1. Individual subject performance during the radial layout session (each outcome was averaged over 30 assisted or unassisted trials).

	Success Rate (%)		Movement Time (s)		Distance Ratio	
	Assisted	Unassisted	Assisted	Unassisted	Assisted	Unassisted
1	100	90	6.0	8.8	2.3	3.6
2	100	96.7	5.0	7.2	3.3	3.3
3	100	100	3.7	4.8	2.6	3.5
4	100	100	3.9	5.3	3.2	4.7
5	100	100	6.0	6.8	2.9	2.7
6	100	100	3.7	4.8	5.5	6.1
7	100	100	5.5	6.1	3.0	2.4

Table 2. Individual subject performance during the random layout session (each outcome was averaged over 30 assisted or unassisted trials).

	Success Rate (%)		Movement Time (s)		Distance Ratio	
	Assisted	Unassisted	Assisted	Unassisted	Assisted	Unassisted
1	96.7	80	7.5	10.4	2.9	2.9
2	100	96.7	6.5	7.9	3.2	3.0
3	100	100	4.9	5.5	2.2	2.2
4	100	100	4.9	6.1	2.9	2.9
5	100	96.7	7.5	9.4	2.1	1.6
6	100	100	4.6	4.7	3.1	3.1
7	100	100	4.3	5.2	2.1	2.2

time, and distance ratio (mean ± standard deviation) for the participants were 100% ± 0%, 4.8 ± 1.1 seconds, and 3.3 ± 1.0, respectively, when the assistance techniques were applied; and 98.1 ± 3.8%, 6.3 ± 1.5 seconds, and 3.8 ± 1.3, respectively, when the algorithm was not present. During the random layout session, the average success rate, movement time, and distance ratio for the participants were 99.5% ± 1.3%, 5.7 ± 1.4 seconds, and 2.6 ± 0.5, respectively, when the algorithm was applied, and 96.1 ± 7.3%, 7.0±2.2 seconds, and 2.6 ± 0.6, respectively, when the algorithm was not present. The two-way repeated measure ANOVA revealed that the assistance algorithm significantly reduced movement time and thus improve operation efficiency (main effect of assistance: F(1,6) = 21.33, $p = .004$). Subjects also tended to move along longer paths in the radial layout session than the random pattern session (main effect of session: F(1,6) = 7.51, $p = .03$). There were no main effects on other variables and no interaction effect. Figure 2 shows the comparisons on success rate, movement time, and distance ratio between the assisted and unassisted trials for both sessions.

Discussion

Previous studies have demonstrated the effectiveness of variations of sticky icon concept, target expansion, and target prediction in improving target acquisition performance among able-bodied individuals and people with motor impairments. This study built upon these previous techniques and integrated three assistance techniques into one algorithm to provide both transition and settling assistance for target acquisition among people with athetosis. Sibenaller showed that people with athetosis spent over 60% of their time acquiring the target as compared to 40% of their time moving towards the target (Sibenaller, 2008). Hwang et al. showed that people with motor impairments often pass over or slip out of their target as they try to position the cursor inside it (Hwang et al., 2004). Thus, in addition to the transition assistance, the algorithm used two techniques (i.e., target expansion and sticky icon concept) to provide settling assistance.

The results of the study showed that there was no main effect on the distance ratio. As the assistance algorithm was developed to assist in acquiring the target instead of improving the trajectory towards the target, this result was expected. Subjects with athetosis in this study tended not to follow the direct paths towards the targets with and without the assistive techniques (about 3 times the direct distance between the targets for the radial layout session and 2.6 times for the random pattern session). Despite the fact that the cursor trajectories were not significantly altered, the total movement time was significantly reduced, ranging from 10% to 31% with an average of 22% for the radial layout session, and 3–27% with an average of 17% for the random layout session. This indicates the three assistance techniques were effective in reducing the overall movement time. Considering the target acquisition occurs countless times in the course of regular computer use, the accumulative effect of such improvements can be significant.

The results of this study were consistent with the simulation results in our previous study where the three techniques

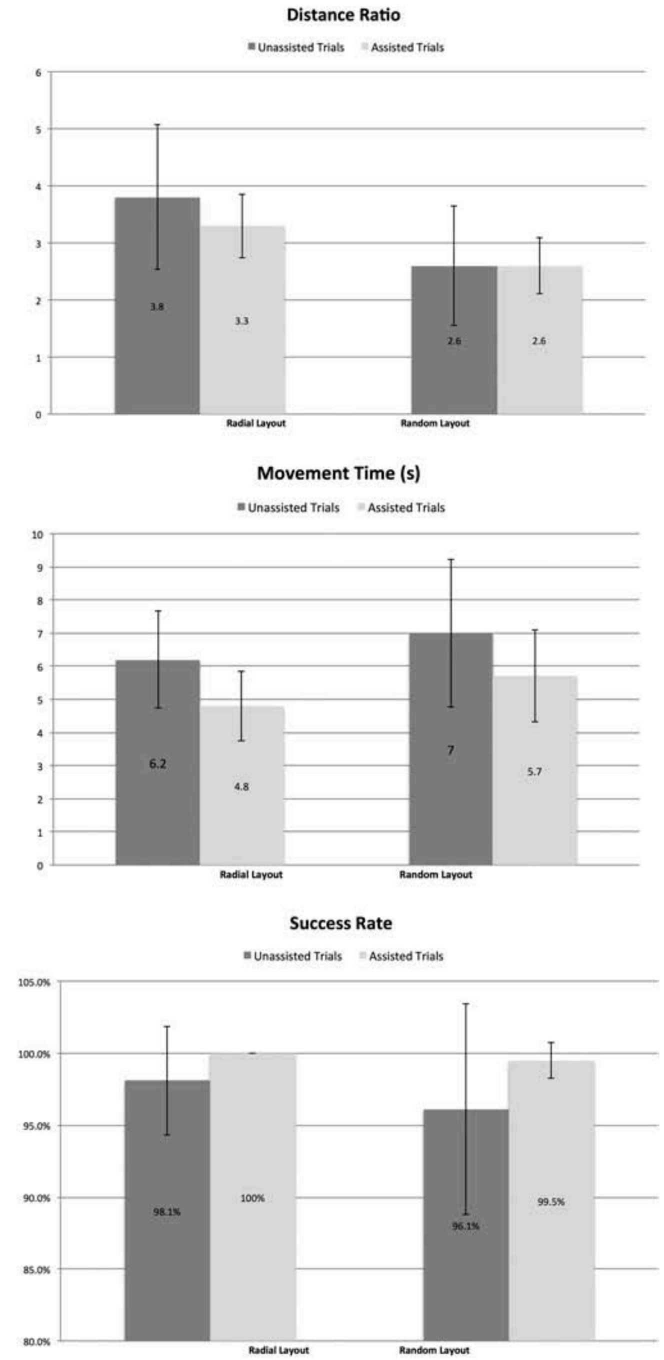

Fig. 2. Comparisons of movement time, distance ratio, and success rate between assisted and unassisted trials for both the radial and random layout sessions.

were able to improve the movement time by 3–29% (Rodriguez et al., 2010). Also similar to the simulation results, the assistance techniques were shown to increase the success rate of target acquisition in this study, though the effect was not statistically significant. Compared with similar work on older adults and other able-bodied populations (Blanch et al., 2004; Hwang et al., 2013; McGuffin & Balakrishnan, 2005), the amount of reduction in the movement time shown in this study was at a similar level. It is worth noting that although all participants in this study reduced their overall movement time when the algorithm was applied, the amount of reduction varied among the participants. Unfortunately, due to the small sample size, we could not observe a trend on how individual characteristics may affect their responses to the algorithm. Our previous simulation results indicated that people with different levels of athetosis may respond differently to the three assistance techniques (Rodriguez et al., 2010).

Despite the fact that the assistance algorithm was evaluated with an isometric joystick as an input device, the algorithm could be potentially applied to standard input devices such as a mouse or trackball. By changing how these devices can be used, we could potentially improve the effectiveness of ordinary input devices for people with athetosis.

There are several limitations to the study. First, there was a ceiling effect of the target acquisition tasks, given the high success rate when no assistance techniques were applied, indicating the tasks we used in this study might be too simple for our participants. Future work should consider testing with different target sizes and more realistic computer interfaces. Second, it is potentially a limitation to the methodology that assisted and unassisted trials were randomly interspersed, and participants did not have a chance to become accustomed to one or the other mode of operation of their joystick. Future work may need to train users with both methods of operation ahead of time and randomize the block of assisted and unassisted trials instead of individual trials. Third, the study protocol was not designed to investigate the effectiveness of individual assistance techniques. Future study protocol could include testing individual assistance techniques and their combinations to identify the best assistance techniques for people with athetosis. Fourth, the sample size was small, which prevented us from further investigating if people with different levels of athetosis may respond to the assistance techniques differently. Finally, the testing scenarios did not include realistic user interfaces. The radial layout simulated typical user interfaces where a number of icons are displayed for selection, while the random layout simulated user interfaces where targets may randomly appeared for selection such as popup interfaces. Future work should include more realistic testing scenarios including buttons, menus, and icons on regular and popup interfaces.

Conclusion

We have presented a quantitative study of a target acquisition assistance algorithm for people with athetosis. Our results show that the assistance algorithm can improve the efficiency of target acquisition tasks and potentially promote computer access among this population. The study has laid a foundation for further investigation into the creation of accessible user interfaces that facilitate target acquisition for people with athetosis.

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