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Research Article

Analysing Ocular Parameters of Users with Cerebral Palsy for Developing Gaze Controlled Interface

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Abstract

Purpose: To investigate response to visual stimuli and visual search patterns of users with cerebral palsy and using that information to facilitate developing eye gaze controlled interaction system.

Methodology: Conducted two studies using eye gaze tracker – the first study analyzed gaze positions for a visual stimulus rendered for 2 secs while the second study analyzed sequence of selecting elements on an eye gaze controlled graphical user interface.

Findings: Users with cerebral palsy adopted a nearest neighbourhood search strategy instead of a top to bottom and left to right strategy like their able-bodied counterparts. They require a target greater than 50 px × 50 px (1.13° × 1.10° of visual angle) size for gaze controlled interface. Users with cerebral palsy have more uncontrolled saccadic gaze movement compared to their able-bodied counterparts. A median filter worked faster than an averaging filter for processing raw gaze data.

Research Implication: Results from the study can be used to design gaze controlled graphical user interface for users with cerebral palsy. Frequently used screen elements should be clustered together and minimum target size should be greater than 50 px.

Originality: Investigation of visual search patterns of users with cerebral palsy in an eye gaze controlled graphical user interface.

Keywords: *Cerebral Palsy; Gaze Controlled Interface*

Introduction

This paper investigates eye gaze movement and fixation patterns of a set of users with severe speech and motor impairment due to cerebral palsy for developing gaze controlled interface for them. Our target users used eye pointing for non-electronic communication board. They could not use any other assistive devices like trackball or push button switch due to physical impairment and we aimed to develop a direct manipulation pointing interface that would be faster to use than scanning interfaces. We undertook a series of three studies to understand their capability of using an eye gaze controlled interface, their preferred area on screen and visual search pattern and finally developed a gaze controlled software.

Eye tracking is the process of measuring either the point of gaze (where one is looking) or the motion of an eye relative to the head. An eye tracker is a device for measuring eye positions and eye movement. Most commonly used non-invasive eye gaze trackers use pupil centre and corneal reflection technique [1]. The eye gaze tracker has inbuilt Infrared LED (Light Emitting Diode) that illuminates the eye and infrared-sensitive video takes rapid pictures of eye. The LED reflects small amount of light off the cornea and through the pupil onto the retina. The bright pupil allows image processor to locate centre of pupil. The eye gaze tracker can then locate where the person is looking on the screen based on the relative positions of the pupil centre and corneal reflection within the video image of the eye. A simple calibration procedure that requires users to follow (means staring at) a shape around screen or a designated position in space tunes parameters for each individual user with respect to a two-dimensional screen or three dimensional space. However there also exist eye gaze trackers that utilise cameras in visible spectrum like webcam or high speed video cameras although those systems are either less accurate (for webcam) or costlier (for high speed video cameras) than infrared trackers.

Our end users were teenage students with cerebral palsy with various level of spasticity. All children were quadriplegic, wheelchair users, cannot speak and with different levels of capabilities of following instruction. We could not interview in detail about their medical condition due to ethical issues and unavailability of information. Cerebral palsy manifest different degrees of impairment of muscle movement, cognition and vision and it is individualistic in nature. Researchers already investigated visual function in children and reported presence of nystagmus in less than 10% in one representative sample [2] and about 72% in another sample [3]. Nystagmus was also accompanied by loss of visual acuity, contrast sensitivity, strabismus and Fazzi [3] reported that "clinical expression of cerebral visual impairment can be variable" requiring a case by case analysis of end users. There is already a plethora of commercial products [4,5] available for electronic gaze controlled interface. Most research for children with cerebral palsy was concentrated on developing applications like augmentative and alternative communication aid, menu structure [6,7], home automation application [8] and so on but there is not much reported work on developing application independent gaze controlled interaction technique. Biswas [9] reported a detailed literature survey on state-of-the-art on gaze controlled interfaces and it may be noted that gaze controlled interface require either bigger button size and arrangement [6,7] or automatic zooming feature [10] or coupling with another interaction device [11] to accommodate inaccuracy in gaze tracking and small pursuit gaze movements. Previous research on gaze controlled Augmentative and Alternative Communication (AAC) Aid did not report results on fixation duration, eye gaze movement and visual search pattern of users with cerebral palsy. Rather they tried to adapt a particular feature (like dwell time in OptiDwell system [12]) or proposed extensive teaching [13]. It may be noted that there are a plethora of feature in an interface and interaction system and researchers already tried to adapt system based on particular user group. The SUPPLE project [14] personalizes interfaces mainly by changing layout and font size for people with visual and motor impairment and also for ubiquitous devices. However, the user models do not consider visual and motor impairment in detail and thus work for only loss of visual acuity and a few types of motor impairment. The AVANTI project [15] provides a multimedia web browser for people with light, or severe motor disabilities, and blind people. It distinguishes personalization into two classes - static adaptation which is personalization based on user profile and dynamic adaptation that is personalization following the interaction pattern (e.g. calculating error rate, user idle time etc. from usage log) with the system.

However, there is not much reported work on analysing visual search pattern for users with cerebral palsy and using that information in developing gaze controlled interface. Traditional visual search studies [16] require feedback from users in the form of a keypress or voice command, which could not be available from users with severe speech and motor impairment. Developing a visual search study is itself a challenge for users with cerebral palsy. This paper attempts to design such a study and utilized it to develop a gaze controlled interaction system and a few guidelines for designing interface for such users. In the remaining part of the paper, we have described three user studies to investigate ocular parameters and using those to develop a gaze controlled system.

Pilot study- Comparing pointing devices

Initially, we wanted to evaluate the best pointing device for users with cerebral palsy. We undertook the standard ISO 9241 pointing task (popularly known as Fitts' Law task). We used the following set of interactive devices and following target size and distances.

1. **Trackball:** Orbit Optical Trackball (M/N: M01082) by Kensington Computer Products Group.
2. **Joystick:** Microsoft Xbox 360 Controller.
3. **Stylus:** Bamboo Pad, wireless (SKU: CTH-300) by Wacom Co., Ltd.
4. **Eye Tracker:** Tobii EyeX with an averaging filter and eye blink based selection.

Width of Target		
Pixels	**Size (in mm)**	**Arc Angle**
40	14.6	3°
45	18.7	3.4°
55	20.4	4.1°
60	22.3	4.5°
Distance of Target from Centre of Screen		
Pixels	mm	Arc Angle
65	24.2	4.8°
120	44.6	9.0°
200	74.2	14.8°
315	116.8	23.2°

Table 1: *Target size and distances.*

However, the particular user group we worked with, could not undertake any pointing task with trackball, joystick or stylus and could point to target using eye gaze but could not select target by blinking. We managed to record less than 20 pointing tasks only with gaze controlled interface even after working with 8 participants with cerebral palsy and hence, could not make a traditional index of performance calculation and movement time vs index of difficulty graph. We noted the following issues with the interaction devices.

- The stick part of the Joystick was small for them to hold
- The button to initiate click action was small
- They cannot synchronously use a finger or hand to move the joystick and pressing the click-action button
- The Trackball is small and have to be scrolled multiple times to complete a pointing task, resulting in too many sub-movements and random movement of cursor on screen
- Holding the stylus was difficult because of their limited motion
- Users had difficulty in moving eye gaze to smoothly move the cursor on screen
- Users could not blink or press another hardware switch synchronously to make a selection in gaze controlled system.

In the following two studies we investigated fixation pattern and eye gaze movement of users with cerebral palsy and compared it with their able bodied counterpart.

Study 1 – Analyzing fixation pattern with respect to visual stimuli

This study investigated whether our end users can fixate attention to a visual stimuli and the duration of their saccadic eye gaze movement before a gaze tracker detects a fixation near the stimuli. We also undertook comparative analysis between users with cerebral palsy and able bodied counterpart of the eye gaze locations recorded by the eye gaze tracker with respect to a visual stimulus.

Participants: We collected data from 12 participants – 6 participants (3 male, 3 female, age range 13 to 15 years) were users with cerebral palsy while the rest were able bodied students.

Material: We used an Intel NUC computer running Windows 7 operating system and a 15" display for displaying stimulus. Eye gaze was recorded using a Tobii Pro X3 eye gaze tracker and a bespoke software written using the Tobii SDK.

Design: The study displayed a 5 mm × 5 mm white stimulus at a random position in a black background for 2 secs and then a blank screen for 2.5 secs. The process was repeated for 5 minutes for each participant.

Procedure: Initially participants went through the 9 points calibration procedure of the Tobii gaze tracker. Then they were only instructed to fixate attention on the white stimuli as soon as it appeared on screen.

Results: Initially we investigated eye gaze positions of participants while the visual stimulus was shown on screen. We calculated the offset (difference) of the position of recorded gaze positions and the stimulus while it was visible on screen. Figure 1 below plots the histograms of x and y deviations for both user groups – blue bars represent users with cerebral palsy while orange bars represent their able-bodied counterpart.

__Figure 1:__ Comparing eye gaze positions with respect to visual stimuli.

It may be noted that the peak occurs between -50 and +50 pixels indicating both group could fix attention on visual stimulus and the eye gaze tracker was able to record it. However, the standard deviation of offsets was almost 2 times higher for the spastic group than their able bodied counterpart. We also calculated correlation between the distance of the stimuli from centre of screen and mean offset and angular deviation of the visual stimuli and mean offset but the coefficients were less than 0.3 for both groups of users.

Figure 2 below shows a cumulative histogram of the offsets. In the graph, point <x,y> denotes that y% of all saccades ended within x pixels from the centre of the stimuli. This graph can be used to optimize size of target for gaze controlled interface. If the target size is more than 50 pixels (1.13° × 1.10° of visual angle) then the probability of selecting a target through a saccade within the target area increases by 25% and if the target is more than 100 pixels then the probability increases by 35% and so on.

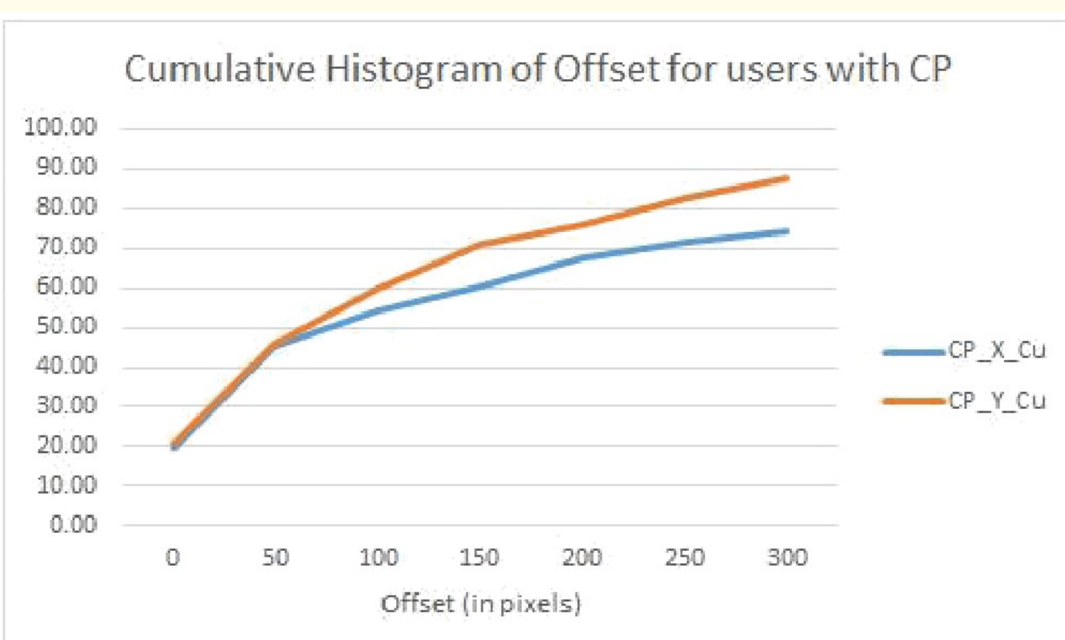

__Figure 2:__ Cumulative histogram of offset.

Next we investigated the minimum time required to record eye gaze position within 50 pixels of the stimulus. Instead of the raw eye gaze position, we compared performance of an averaging and median filter. The filter runs a sampling window of latest 10 gaze locations and return either the arithmetic mean or median of the latest 10 eye gaze position. For both groups, the peak occurred at 400 msecs for median filter and at 450 msecs for averaging filter. We also noted that within 1500 msec, we could record a gaze position near the stimulus for 82% of cases for users with cerebral palsy and 98% cases for their able-bodied counterpart.

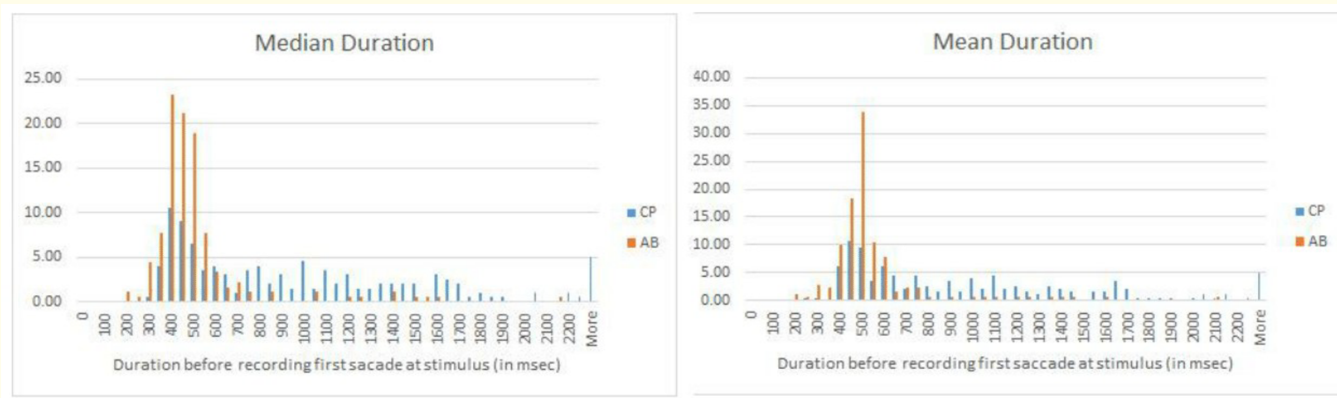

Figure 3: *Comparing visual search time for stimuli.*

Discussion

This study aims to investigate response to visual stimuli by users with cerebral palsy with an aim to calibrate gaze controlled cursor control device. The study demonstrates that users with cerebral palsy could fixate attention although have more uncontrolled saccadic gaze movements than their able-bodied counterparts. The offset did not correlate with screen position or angular deviation of the stimuli. The size of target can be optimized by analysing the offsets. We also compared a median and mean filter to reduce effect of uncontrolled gaze movements and noted that both able bodied and spastic participants can fixate attention to visual stimuli within 1.5 secs in more than 80% cases. The median filter found to response 50msec faster in detecting fixation compared to the averaging filter.

Study 2 – Analyzing visual search pattern

The third study aimed to compare visual search patterns between users with cerebral palsy and their able-bodied counterpart. We also investigated if our end users prefer any particular area of screen than other areas, which information can be used to optimize interface design for them.

Participants: We collected data from 20 users – twelve of them were users with cerebral palsy (6 male, 6 female, age range 13 to 16 years) and eight able-bodied students.

Material: We used same set of material as the previous study.

Design: We displayed a set of ten balloons (Figure 4) on the screen. Each balloon was 103 × 112 pixels in size. Participants were requested to point and click on all balloons. The balloons disappeared on clicking. When all balloons disappeared, a new set of ten balloons appeared on screen. We did not specify any particular order to select balloons.

We implemented the following algorithm to point and click on the balloons using eye gaze. The gaze tracker was recording eye gaze positions at 60 Hz. We implemented a function that calculated the median of gaze position every 300 msec. The cursor moved on the screen based on the median gaze position. The balloon nearest to the position of the cursor was enlarged to 1.5 times its size. If the gaze dwell near or on the balloon for 1.5secs, it was selected and disappeared from screen. The 1.5 secs dwell time was selected based on the previous study to ensure participants intentionally selected a pointing target.

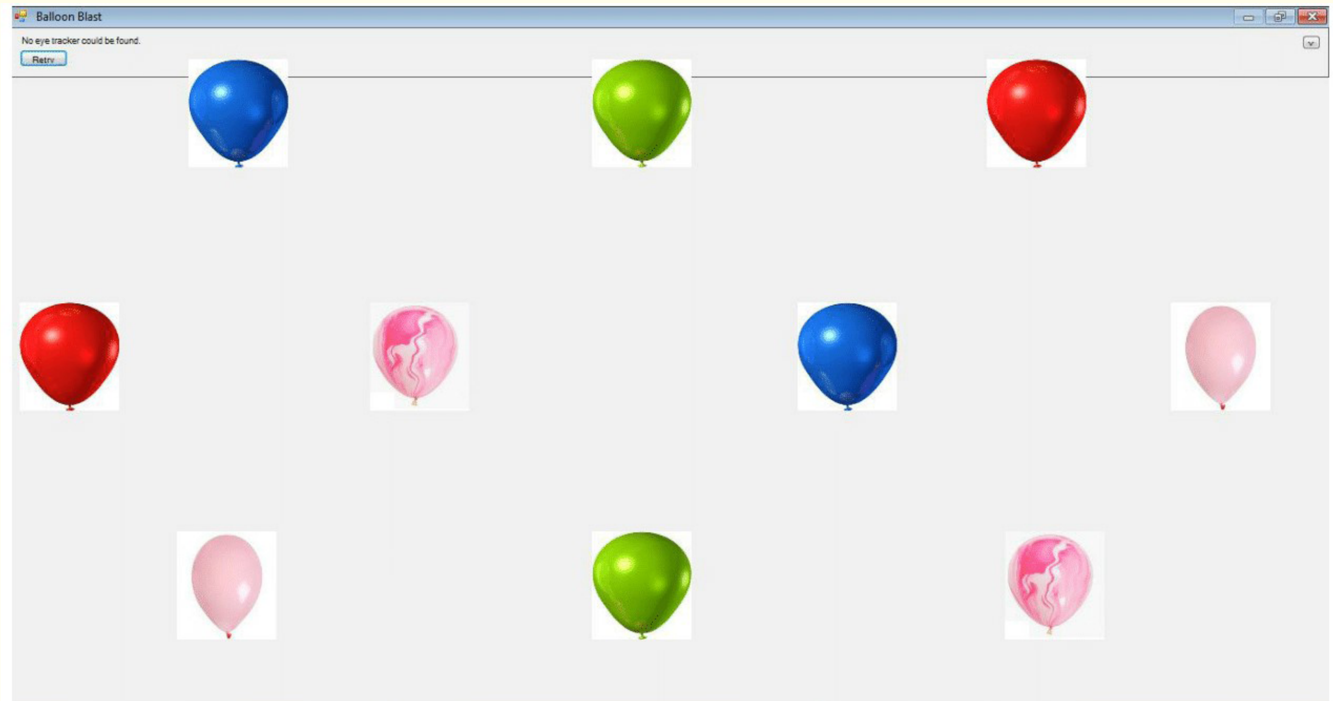

Figure 4: *Design of task for analysing visual search pattern.*

Procedure: Initially, participants undertook the 9 points calibration routine provided by Tobii SDK. Then they undertook a training session and after they understood the task, they were instructed to point and click all balloons. We recorded at least 15 pointing and clicking tasks from each participant.

Results: We have investigated the following four dependant variables.

1. **Pointing and selection times for each position:** Total time spent between a selection and the next one.
2. **Frequency of first choice:** Which position was first selected and how many times.
3. **Frequency of selection:** How many times each position was selected.
4. **Patterns:** Sequences of selection.

For each dependant variable, we compared performances of users with cerebral palsy with their able-bodied counterparts. We have used the following terminology to designate different screen positions.

TL: Top Left		TM: Top Middle	TR: Top Right
ML: Middle Left	MCL: Middle Centre Left	MCR: Middle Centre Right	MR: Middle Right
BL: Bottom Left		BM: Bottom Middle	BR: Bottom Right

Figure 5: *Nomenclature of target positions.*

Pointing and selection Times were significantly lower for able bodied users compare to users with cerebral palsy [t(0,9) = -12.95, p < 0.001]. The variance was 38 times higher for users with Cerebral Palsy indicating they occasionally took long time to make a selection.

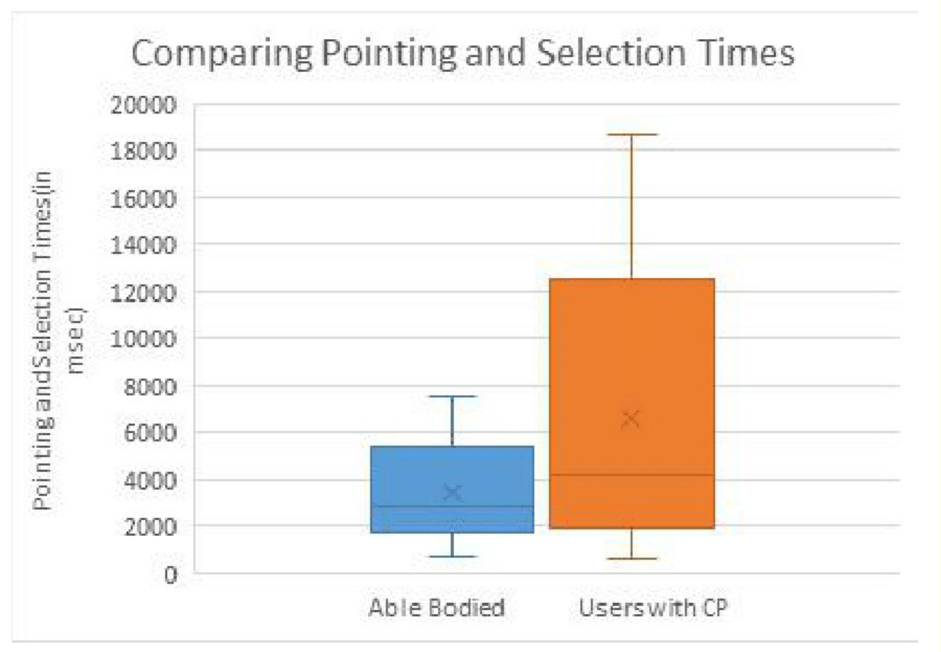

Figure 6: *Box plot of pointing and selection times.*

We analysed the pointing and selection times for each position of targets for both user groups and in figure 7 below indicated lower selection times with bigger font size. It may be noted that users with cerebral palsy took least time to select balloons at Top Right, Middle Centre Right and Bottom Middle positions while the able bodied group took least time for Bottom Left, Middle Centre Left and Middle Right positions.

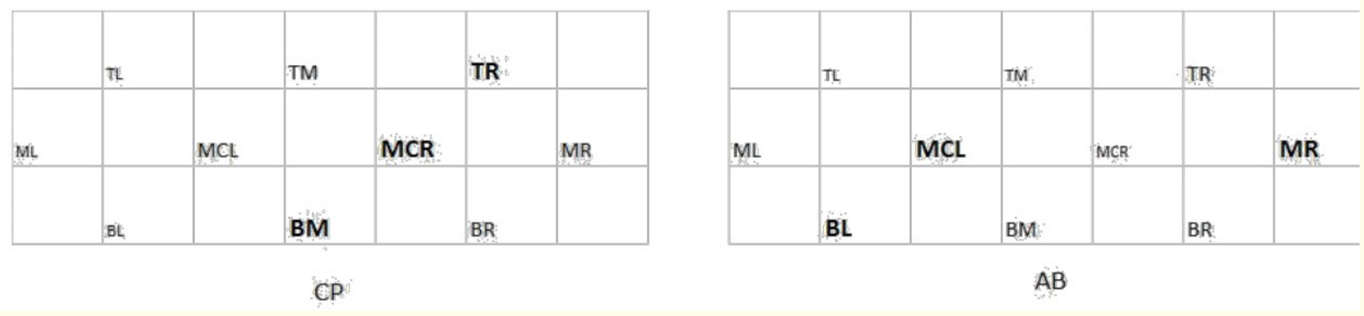

Figure 7: *Comparing pointing and selection times with respect to screen positions between users with cerebral palsy and their able bodied counterparts.*

Figure 8 below indicates the frequency of selection of first position by drawing a black border around the three most frequent positions. Users with cerebral palsy most of the time first selected one of the MCL, MCR and TR buttons while their able bodied counterparts most of the time first selected TL, TM and MCR buttons.

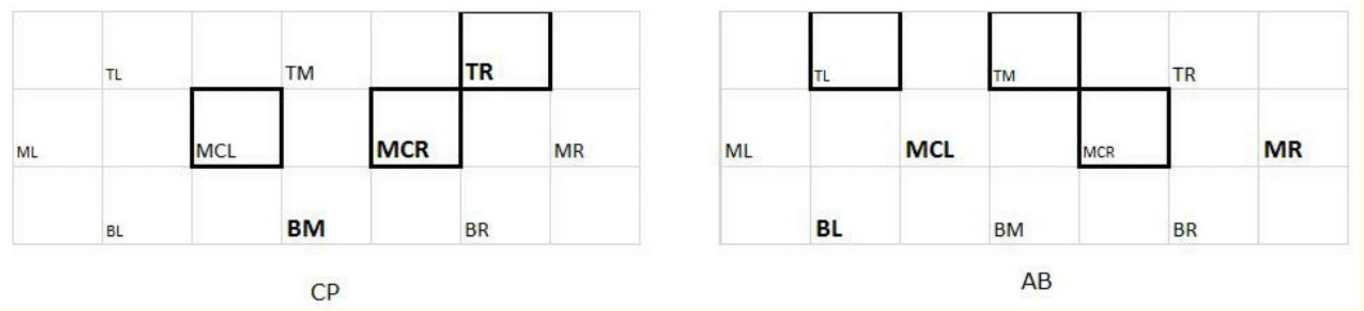

Figure 8: *Comparing frequency of first selections with respect to screen positions between users with cerebral palsy and their able bodied counterparts.*

Although participants were instructed to select all 10 balloons but users with cerebral palsy often could not select all buttons in the screen. The standard deviation among the number of selections summed up for each individual position is only 1 for able bodied users while it is 8.8 for users with cerebral palsy. Figure 9 below indicates the total number of selections according to position using colour coding. The green colour indicates the first three preferences, yellow next four and red indicates the least three.

Figure 9: *Comparing total number of selections with respect to screen positions between users with cerebral palsy and their able bodied counterparts.*

The number of selections and average pointing and selection times with respect to each position was negatively correlated (r = -0.29) for users with cerebral palsy and positively correlated (r = 0.43) for able-bodied users. None of these correlations were significant at p < 0.5.

Finally, we analysed the patterns in sequence of selections – means we investigated how many times users select button A after button B for all pairs of values of A and B and similarly all possible patterns of selections consisting three consecutive selections. Figure 10 below shows the top most 2-buttons and 3-buttons sequences using blue and brown arrows respectively, the thickness of the arrow indicates the frequencies of occurrences of the patterns, which is also furnished in table 2 below.

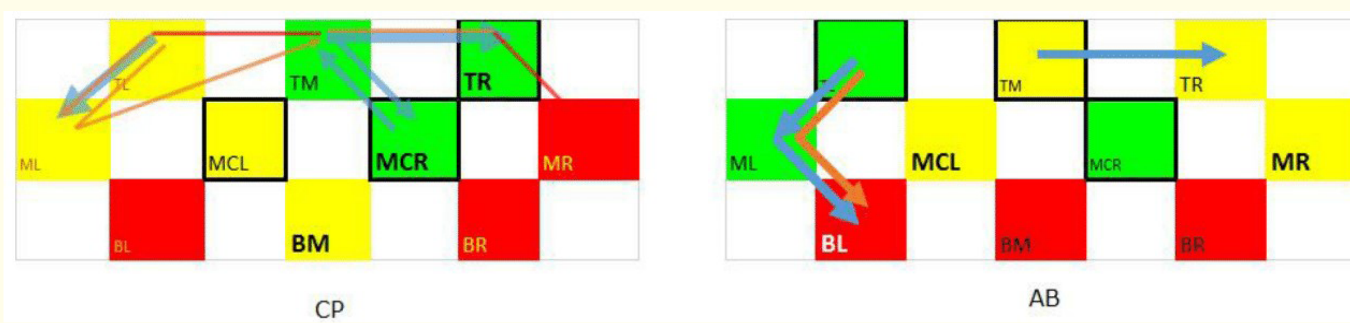

Figure 10: *Comparing patterns of selections with respect to screen positions between users with cerebral palsy and their able bodied counterparts.*

CP	Able-Bodied		
Patterns	**#Selections**	**Patterns**	**#Selections**
TL-ML	12	ML-BL	10
TM-TR	12	TL-ML	10
TM-MCR	8	TM-TR	9
MCR-TM	8		
TL-ML-TM	4	TL-ML-BL	9
TM-TR-MR	4		
TM-TL-ML	4		

Table 2: *Comparing patterns of selections with respect to screen positions.*

Discussion

The study shows users with cerebral palsy took longer with more variance to point and select than their able-bodied counterparts. We also noted a left to right and top to bottom search strategy for able bodied users while the frequency of total selection, first selection and visual search patterns indicate a nearest neighbourhood strategy for users with cerebral palsy. The nearest neighbourhood strategy means users selected the nearest target from their present position instead of going through a serial scanning technique. The task initiated with the focus at the middle of the screen and then it can be noted that MCR, TR and TM positions were mostly selected and reaction time was also lowest for MCR, TR and BM positions. The highest observed patterns also indicated this nearest neighbourhood strategy instead of left to right and top to bottom search strategy. This search strategy could be leveraged while developing software interface for users with cerebral palsy, earlier Fleetwood [16] reported similar strategy in an icon searching task even for able bodied users. However, the pointing and selection times do not seem to related to the number of selections. It may indicate users' search strategy is independent of the time they require to select a target, which perhaps depend on the settings of the cursor control algorithm.

Gaze controlled cursor

Finally, we developed the following algorithm for controlling an on-screen cursor using eye gaze. Our gaze tracking system records the eye gaze positions continuously (refer point A in figure 11) and takes the median of the pixel locations in every 450 msecs to estimate the region of interest or saccadic focus points (refer point B in figure 11). The median was less susceptible to outliers than arithmetic mean in case the eye gaze tracker briefly lost signal. We simulate the eye movement using a Bezier curve that smoothers the cursor movement between two focus points as we wanted to make the cursor movement looking similar to an existing cursor control devices like mouse or trackball. It then pushes the focus points into a stack and the Bezier curve [17] algorithm interpolates points in between two focus points (refer point B in figure 11). The pointer is drawn at each interpolated points in every 16 msec to visualize a smooth on-screen movement (refer point C in figure 11).

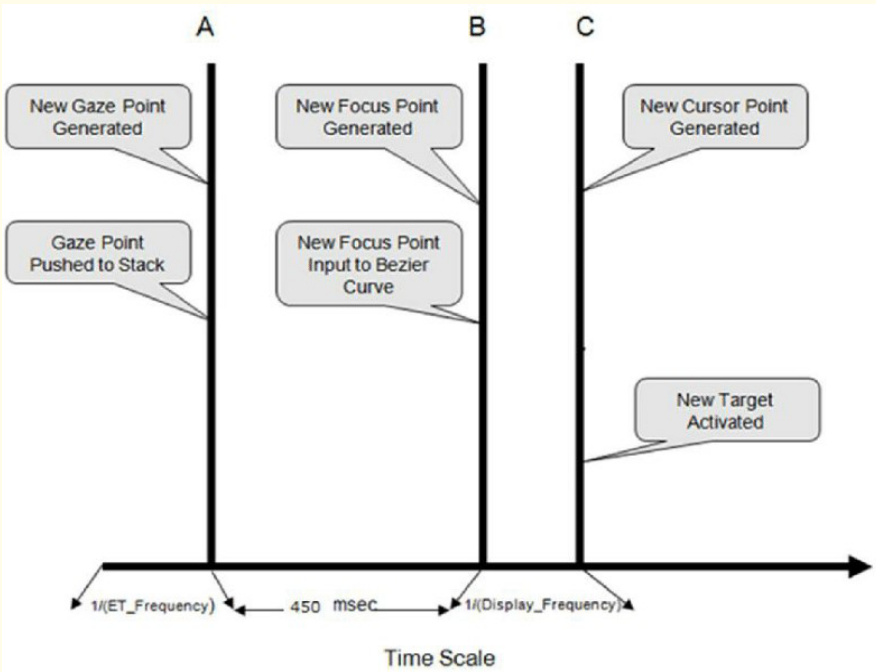

Figure 11: *Gaze controlled cursor movement algorithm.*

Conclusions

This paper presents three studies involving users with cerebral palsy for analysing their visual search pattern and developing gaze controlled interface. The first study found that this particular group of users could not use trackball, joystick and stylus and prefer to use eye pointing only. The second study identified evidence similar to nystagmus in their eye gaze movements requiring appropriate filtering technique. We noted that a median filter can identify fixation with respect to visual stimuli faster than an averaging filter. Finally, we identified a difference in visual search patterns between users with cerebral palsy and their able-bodied counterpart. We noted that unlike their able-bodied counterparts, users with cerebral palsy did not follow a left to right or top to bottom strategy, rather investigated targets nearest to their contemporary gaze position.

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Bibliography

1. Duchowski AT. "Eye Tracking Methodology". Springer (2007).
2. Vasanth J., *et al*. "Visual Function Status in Children with Cerebral Palsy". *Optometry and Visual Performance* 2.3 (2014): 251-253.
3. Fazzi E., *et al*. "Spectrum of Visual Disorders in Children with Cerebral Visual Impairment". *Journal of Child Neurology* 22.3 (2007): 294-301.
4. Communicate with the world using the power of your eyes (2017).
5. Eye-gaze control technology (2017).
6. Mario H., *et al*. "Selecting with gaze controlled pie menus". Proceedings of the 5th Conference on Communication by Gaze Interaction – Gaze Interaction For Those Who Want It Most COGAIN (2009).
7. Majaranta P., *et al*. "Text Editing by Gaze: Static vs. Dynamic Menus". Proceedings of the 5th Conference on Communication by Gaze Interaction– Gaze Interaction For Those Who Want It Most COGAIN (2009).
8. Castellina E., *et al*. "Environmental Control Application compliant with Cogain Guidelines". Proceedings of the 5th Conference on Communication by Gaze Interaction – Gaze Interaction for Those Who Want It Most COGAIN (2009).
9. Biswas P and Langdon P. "Multimodal Intelligent Eye-Gaze Tracking System". *International Journal of Human-Computer Interaction* 31.4 (2015): 277-294.
10. Bates R. "Multimodal Eye-Based Interaction for Zoomed Target Selection on a Standard Graphical User Interface". Proceedings of INTERACT (1999).
11. Zhai S., *et al*. "Manual and Gaze Input Cascaded (MAGIC) Pointing". ACM SIGCHI Conference on Human Factors in Computing System (CHI) (1999).
12. Nayyar A., *et al*. "OptiDwell: Intelligent Adjustment of Dwell Click Time". Proceedings of International Conference on Intelligent User Interfaces (IUI'17) (2017).
13. Borgestig M., *et al*. "Eye gaze performance for children with severe physical impairments using gaze-based assistive technology-A longitudinal study". *Assistive Technology* 28.2 (2016): 93-102.

14. Gajos KZ., *et al*. "Automatically generating user interfaces adapted to users' motor and vision capabilities". ACM symposium on User interface software and technology (2007): 231-240.

15. Stephanidis C., *et al*. "Adaptable and Adaptive User Interfaces for Disabled Users in the AVANTI Project". Intelligence in Services and Networks, LNCS-1430, Springer-Verlag (1998): 153-166.

16. Fleetwood MF and Byrne MD. "Modeling the Visual Search of Displays: A Revised ACT-R Model of Icon Search Based on Eye-Tracking Data". *Human-Computer Interaction* 21.2 (2006): 153-197.

17. Salomon D. "Curves and Surfaces for Computer Graphics". Springer Verlag (2005).

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