A Low-Cost, Computer-Interfaced Drawing Pad for fMRI Studies of Dysgraphia and Dyslexia

Frederick Reitz[1]*, Todd Richards[2], Kelvin Wu[1], Peter Boord[2], Mary Askren[2], Thomas Lewis[1], and Virginia Berninger[2]. 1 [Instrument Development Lab, Center on Human Development and Disability, University of Washington, Seattle, WA 98195, USA]. 2 [Integrated Brain Imaging Center, Dept. of Radiology, University of Washington, Seattle, WA 98195, USA]. E-Mails: wuanzinger@gmail.com (K.W.); tnlewis@uw.edu (T.L.); E-Mails: toddr@uw.edu (T.R.); pboord@uw.edu (P.B.); askren@uw.edu (M.A.); vwb@uw.edu (V.B.).
*Author to whom correspondence should be addressed: E-Mail: freitz@uw.edu; Tel.: +1-206-543-9023; Fax: +1-206-616-8580.

ABSTRACT

We have developed a pen and writing tablet for use by subjects during fMRI scanning. The pen consists of two optical fibers routed to the tip of a hollowed-out ball-point pen. The tablet is simply a non-metallic frame holding a paper print of continuously varying color gradients. The optical fibers are routed out of the MRI bore to a light-tight box in an adjacent control room. Within the box, light from a high intensity LED is coupled into one of the fibers, while the other fiber abuts a color sensor. Light from the LED exits the pen tip, illuminating a small spot on the tablet, and the resulting reflected light is routed to the color sensor. Given a lookup table of position for each color on the tablet, the coordinates of the pen on the tablet may be digitized in real-time. While simple and inexpensive, the system achieves sufficient resolution to grade writing tasks testing dysgraphic and dyslexic phenomena.

BACKGROUND

We seek to understand the neural substrates of dysgraphia (a handwriting disorder [1]) and dyslexia. Zakzanis *et al.* [2] and Tam *et al.* [3] have previously developed fMRI-compatible writing devices, though for many studies of dyslexia/dysgraphia, fine resolution is less centrally important than the ability to qualitatively grade responses and correlate them with brain activation, and a very simple, inexpensive system such as the one described herein suffices.

METHODS

Light is launched into, and collected from, a pair of 2 mm, multimode, plastic optical fibers. The fibers are epoxied in place within the emptied plastic shell of a disposable ball-point pen, in turn epoxied perpendicularly into the drilled-out center of an acrylic plate. The "pen" prior to securing with glue and enclosure in heat-shrink tubing is shown in Figure 1.

Fig 1. Pen with 2 optical fibers

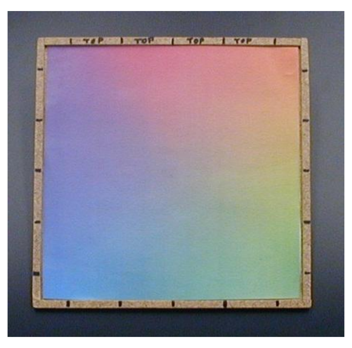

Fig 2. Color map print

The color sensor is a TAOS TCS230 color light-to-frequency converter. Light from a Luxeon Rebel "Neutral White" Star LED is contact-coupled to the map-illumination fiber, while the scattered-light-collecting fiber is abutted to the light-sensitive region of the TAOS sensor. Resulting pulse trains from the sensor are collected by a counter on a National Instruments NI PCI-6025E board and read into custom LabVIEW software.

The surface "written" upon is a continuously varying color map (Figure 2) printed on conventional printer paper.

The subject was shown stimuli via projection onto a mirror above the head coil. The pad is raised on a 30 degree wedge of foam for comfort (Figure 3).

Fig 3. Tablet in use

When run, the program turns a specified file of calibration readings and a desired number of pixels per axis into a lookup table of X-Y positions for each such RGB value, again saved to a file. Given such a table, the software can accept and display incoming data as a character being drawn on the screen in real time (Figure 4).

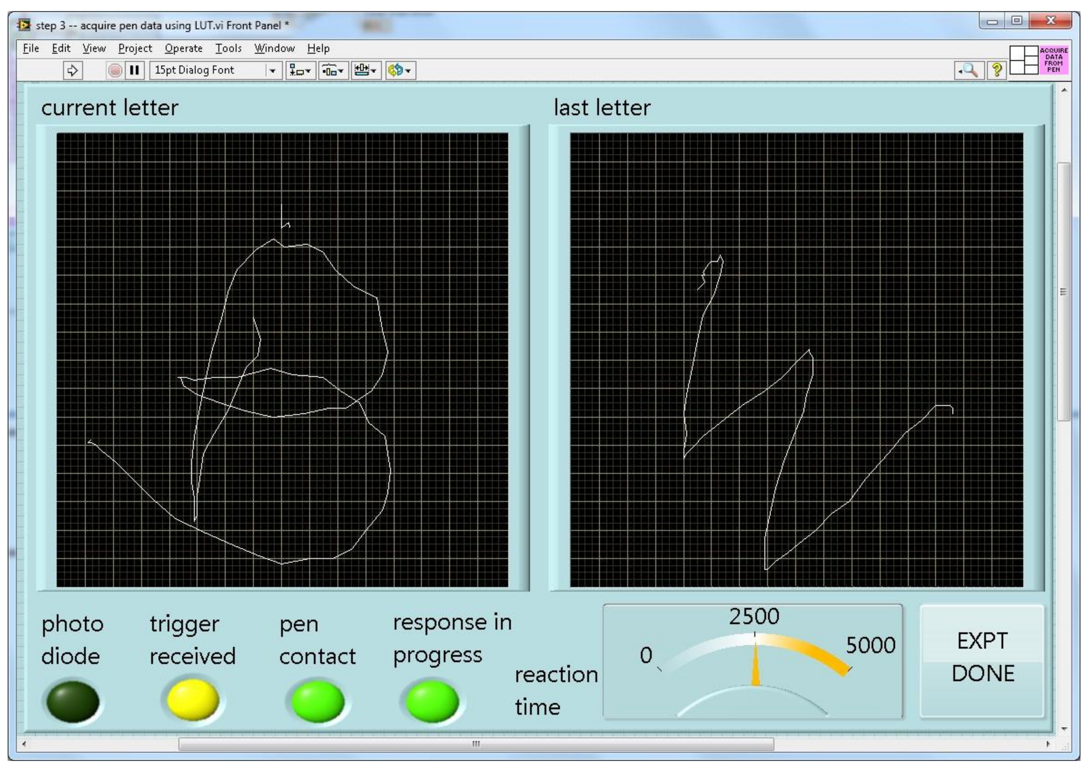

Fig 4. Real-time handwriting digitization

RESULTS

Calculated pixel positions showed a sub-pixel variation (standard deviation of ~2.7 mm) uniformly over the center-most 50% of each range field, increasing to ~5.4 mm over the outer-most quadrants of each axis. Time lag between pen motion and display of the stroke on the screen is ~130 ms at present.

To assess whether the writing task using the pen induces head motion, the FSL software tool MCFLIRT [4] was used to assess head motion as a mean absolute displacement and as a relative displacement using the fMRI head signal during 13 minutes each of reading and writing tasks using our pen inside the scanner. Our preliminary data shows little difference between the motion during the reading task compared with the writing task, suggesting that use of the device does not necessarily increase head motion materially (Table 1).

Table 1. Head remaining still

Subject	Task	Mean (mm)	Rel. (mm)
1	reading	0.45	0.07
	writing	0.47	0.08
2	reading	0.19	0.06
	writing	0.22	0.06

The functional connectivity maps were created from fMRI scans of 11 year old subjects with either dysgraphia or dyslexia (Figure 5) while performing the writing task using the pen described herein. This connectivity analysis was based on a seed region in Broca's area on the left side of the brain. The clusters of activity are mainly in Broca's area, motor area, angular gyrus and frontal areas. Our preliminary results show more connections from Broca's area in the dyslexic subject than in the dysgraphic subject, but more data is required to establish statistical significance.

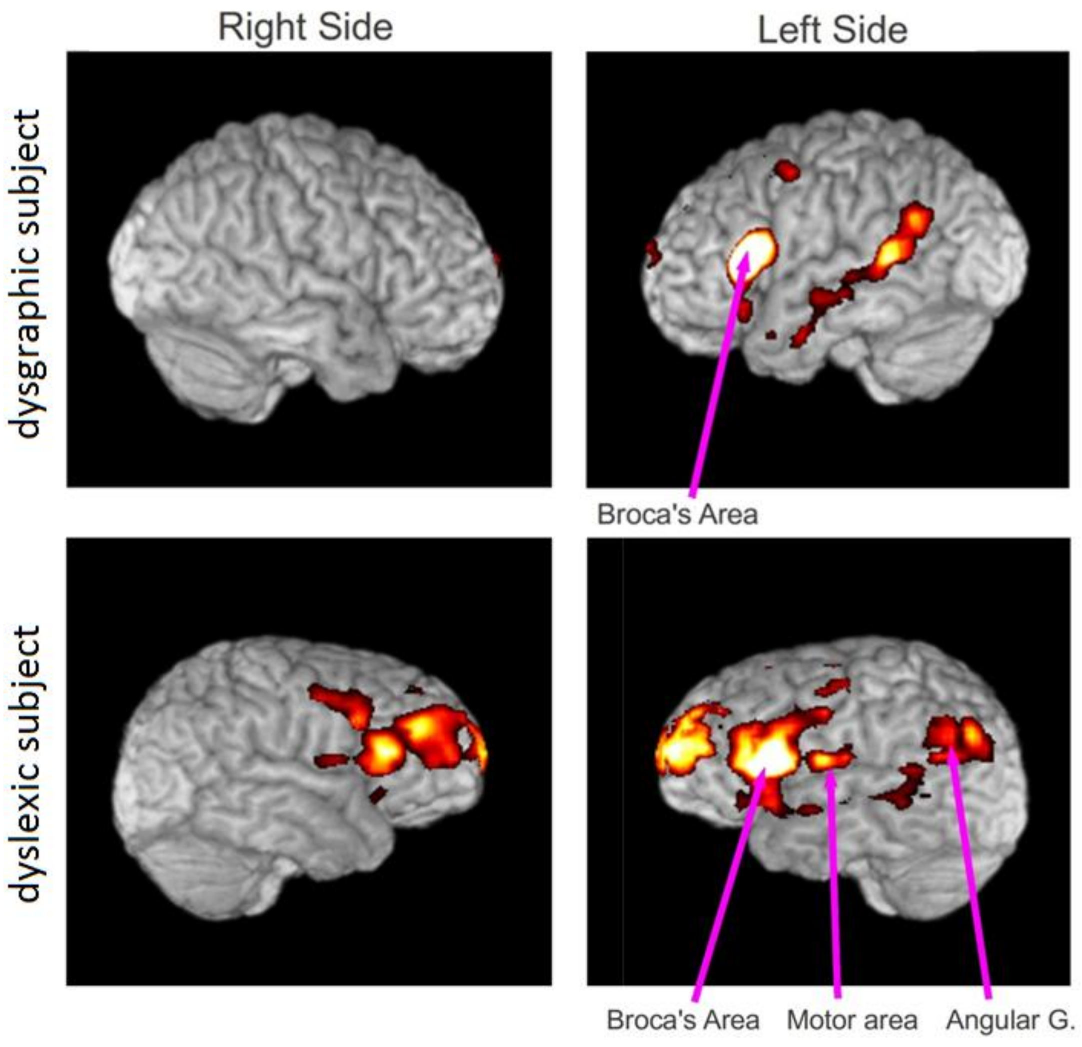

Fig. 5 Dysgraphia vs dyslexia

CONCLUSIONS

In sum, we find the device as implemented usable for fMRI studies of dyslexia and dysgraphia. Construction was straightforward and inexpensive (~$100 of parts beyond the cost of the LabVIEW development environment and data acquisition card). Use of the device was comfortable, did not induce prohibitive motion artifact during fMRI, and achieved high enough spatial (several mm) and temporal (~30 points per second with ~130 ms lag) resolution to legibly discern dyslexic/dysgraphic phenomena.

ACKNOWLEDGEMENTS

Acknowledgments

This project received engineering support from the UW CHDD IDL funded by NIH Grant HD002274, and financial support from the NIH/NICHD Grant 1P50HD071764.

REFERENCES

1. Dyslexia A to Z. Available online: http://www.dyslexiaa2z.com/learning_difficulties/dysgraphia/dysgraphia_definition.html (accessed on 1 June 2012).
2. Zakzanis, K.K.; Mraz, R.; Graham, S.J. An fMRI study of the trail making test. *Neuropsychologia* **2005**, *43*, 1878–1886.
3. Tam, F.; Churchhill, N.W.; Strother, S.C.; Graham, S.J. A new tablet for writing and drawing during functional MRI. *Hum. Brain Map.* **2011**, *32*, 240–248.
4. Jenkinson, M.; Bannister, P.R.; Brady, J.M.; Smith, S.M. Improved optimisation for the robust and accurate linear registration and motion correction of brain images. *NeuroImage* **2002**, *17*, 825–841.