Cognitive Prosthetics and Telerehabilitation:
Approaches for the Rehabilitation of Mild Brain Injuries

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Introduction:

The development of cognitive prosthetics closely follows that of treatment for traumatic brain injury. The field of traumatic brain injury originally focused on the needs of individuals who had an obvious serious medical crisis. Hospitalization was required, and frequently neurosurgery was required. Most of these individuals recovered and were able to resume their normal lives.

Cognitive prosthetics was originally developed to address the needs of individuals who require a significant amount of caregiver support even after aggressive cognitive rehabilitation. In the mid-80s, these were individuals who, 2 years after their injury, still had moderate to severe cognitive deficits.

Initially mild traumatic brain injury was not recognized as a significant medical and rehabilitation condition, and was considered outside the purview of traumatic brain injury. Only later was it recognized that individuals without a medical crisis could permanently loose a degree of cognitive functioning sufficient enough to cause cognitive disruption. These were individuals who didn’t need caregiver assistance from the start, but were unable to return to their former level of functioning, particularly in some of the independent activities of daily living including their vocation. Fortunately, cognitive prosthetics has demonstrated its effectiveness in addressing functional cognitive needs of individuals with mild brain injuries. Cognitive prosthetics is also appropriate because it addresses significant social-psychological considerations as well: The use of computer technology is status-enhancing, and an obvious symbol of significant cognitive abilities.

What Is a Cognitive Prosthesis

Cognitive prosthetics is an assistive technology, and was developed by computer scientists working with rehabilitation professionals. Cognitive prosthetics combines complex technology and therapy; it is not sufficient to deliver the technology without the therapist. The first review article on cognitive prosthetics was just published this April (Cole, 1999), and developed a set of criteria for what constitutes a cognitive prosthesis.

- A cognitive prosthesis is designed specifically for rehabilitation purposes.
- A cognitive prosthesis uses computer technology. The hardware which is given to the patient may be changed during the course of treatment, i.e., a desktop computer initially and then a notebook computer. Other hardware may be added and integrated, such as a scanner, pager, or cell phone.
- As such, it is a rehabilitation compensatory strategy, which the patient uses to compensate for acquired deficits. A cognitive prosthesis maximizes the individual's strengths and abilities.
- It directly assists the individual in performing their daily activities, and is thus part of the community-based treatment model. Specific activities are identified by the patient and the treatment team for support and rehabilitation. From the start, the cognitive prosthesis is used on the patient's actual activities and in the environment where these activities are performed. In this way, rehabilitation is superimposed onto and integrated into the patient's actual activities.
- A cognitive prosthesis is highly customizable to the specific needs of the individual patient. This involves three key elements:
    - <u>Customization is required to make the individual effective in performing the task.</u> It takes into consideration the setting(s) where the activity is performed. The patient's environment plays an integral role in identifying the individual's relevant abilities as well as context-specific deficits that need to be addressed.
    - <u>Customization is also required to make the cognitive prosthesis user-friendly to the patient.</u> The features of the prosthesis are adapted to fit the patient's abilities so that no more than 3 half-hour training sessions are required to learn how to use. The cognitive prosthesis enables the patient to successfully perform the target activity without caregiver assistance. These performance criteria are achieved by cycles of software design and testing. The prosthesis is customized to work successfully with the patient's current functional deficits, and does not *require* additional capabilities.
    - <u>Unlike conventional commercial software, it does not provide the patient with additional features that are not clinically indicated and currently addressed.</u> Features are added only as clinical goals are immediately addressed.
- The device collects data while it is being used, and that data is a valuable input to clinical treatment and ongoing assessment. The data enables assessment of the technology, so that it can be fine-tuned. The data also shows the extent to which the cognitive prosthesis actually supports the patient. Often the data will enable the therapist to identify the patient's capabilities.

These criteria distinguish a cognitive prosthesis from electronic aides. While these widely available devices seem to have beneficial capabilities, both the effectiveness and the problems presented by these devices cannot be evaluated.

Why Cognitive Prosthetics Is Needed

Cognitive prosthetics mirrors a growing trend where assistive technology is playing an increasingly important role in cognitive rehabilitation (Rose et al., 1997; Giaquinto & Fiori, 1992; Tate, 1997). The evolution of this role in an area formerly governed exclusively by low-complexity technology and office "talk and practice" methods is reminiscent of the "diagnostic displacement" that occurred when neuroimaging, mainly CT and MRI scanning, showed that it was superior to clinical judgment in localizing brain lesions (Matthews et al., in press). Now, approximately twenty years after the first CT images became widely available, complex and powerful imaging technology is a sine qua non of expert neurological care. The emergence of complex technology in cognitive recovery programs, we believe, is tracing a similar course, and the cognitive prosthesis is a central example in this process.

The rationale for expanding the role of computerized cognitive prosthetics in modern programs of cognitive rehabilitation is similar to the rationale for the ubiquity of neuroimaging technology in neurology and neurosurgery: improved care, efficiency, and proven efficacy in an era of shrinking resources. In particular, there is a growing need in the case of the patient with brain injury to speed the recovery process, to reduce the burden on families and other household members of a patient's disabilities (Marsh et al., 1998), and to lower the costs while improving the efficacy of treatment services.

The current healthcare environment increases the importance of cognitive prosthetics. There is a reduced willingness to fund extensive rehabilitation treatment plans, plus a drive for greater efficiency in the delivery of rehabilitation services. Many individuals may be denied rehabilitation options that exceed cost ceilings or that take too many therapy sessions and resources to achieve. This state of affairs, however, is one for which technology, especially the cognitive prosthesis, offers a powerful solution. A cognitive prosthesis costs less than conventional cognitive remediation, is used largely remotely rather than in a hospital or an outpatient therapy suite, and improves the patient's performance of everyday activities to increase their independence and life satisfaction (Cole et al., 1995; Matthews et al., 1997; Matthews & Cole, 1998).

A Clinical and Research Center for Cognitive Prosthetics and Telemedicine

The Institute for Cognitive Prosthetics (ICP) provides an environment where cutting-edge technologies are developed and integrated into clinical treatment. The ICP staff consists of clinicians, computer scientists, and medical outcomes researchers. Clinicians are able to ask for technology that can increase their effectiveness or a patient's increase in functioning. Computer scientists are able to learn more about the therapists and patients who are the users. Medical outcomes researchers are able to develop new measures and instrumentation. They work together on delivering clinical services to patients and providing services which support the therapists in using our complex assistive technology.

One conclusion of this collaboration is that the patient's setting is often the ideal place for the patient to receive a broad range of rehabilitation services. The patient's setting focuses on the home, office, school, and occasionally the rehabilitation facility. The patient's community is also part of the setting, and is considered in delivering services. However, the patient's setting is not the ideal place for the therapist.

The Institute for Cognitive Prosthetics has developed a set of techniques for providing specialized cognitive prosthetics therapy to the patient's setting. These techniques involve conducting a face-to-face evaluation in the patient's home or office. Arrangements are also made with local clinicians.

Face-to-face contact is important. Videoconferencing enables us to have face-to-face therapy sessions with individuals in their own homes, some of which are 3,000 miles and three time zones away from the therapist. It is important for both the patient and the therapist to see each other. Videoconferencing also allows the therapist to see the patient's work area. Viewing the patient's work area – and asking questions about it – is considered important by the therapists.

Another facet of our treatment is the therapist's ability to work with the patient on the patient's own computer. The therapist uses remote control software on his or her own (therapist's) computer to connect with the patient's computer. The therapist then sees exactly what the patient is seeing. They are able to use the prosthetic technology together during therapy sessions. The therapist is able to leave assignments directly on the patient's computer. The therapist is able to make suggestions about the patient's activities in the most relevant manner. The therapist is also able to leave messages for the therapist, as well as raise questions when they occur to the patient.

Individuals with mild brain injuries often need help on vocational activities. On-site job coaching has many disadvantages. It is symbol of difficulty performing the job. It is often humiliating to the patient-employee. It is often difficult for the job coach who must be available for an opportunity to provide a couple of minutes of assistance. ICP's technology and techniques have developed a means of off-site job coaching. The patient is able to unobtrusively call for assistance. Our experience with office workers, executives, and professionals is that the patient is able to function adequately most of the time, and only occasionally needs assistance.

Therapists find the advantages of this means of treatment are substantial; and as a result, this has become our standard means of working with our patients. The advantages are so substantial that we use it even with those patients who live only a few minutes from our offices.

It is not only patients who can be at a distance from our office. Our therapists can be at a distance as well. We have two therapists who are more than 300 miles from our office. The off-site therapists work with on-site therapists as well as the technical staff. These off-site therapists increase our understanding of the issues involved in working with other healthcare organizations and clinicians.

This research and clinical environment enables us to identify and study a large number of issues in the delivery of computer-based rehabilitation services.

Case studies

Four case studies will be presented at the platform session.

RU – High achiever

RR – Housewife with special needs child

UC – Human services supervisor

RG -- Professional

Discussion

In each of these case studies, conventional cognitive rehabilitation had failed at ameliorating patient priority activities, and cognitive prosthetic treatment was able to achieve success within the first few days of our intervention. In terms of research, it is desirable to have the control of failure followed by rapid success.

There are several reasons for this success. First and most obvious is the technology. Cognitive assistive technology can bridge functional deficits to enable the individual to perform their priority activities. Second, the technology must be accompanied by skilled therapy. This therapy must take advantage of the special features of the cognitive prosthesis. One important facet of this therapy is the ability to augment the cognitive prosthesis. Additional features are introduced to the patient’s cognitive prosthesis as an ongoing part of the treatment plan.

Another set of factors is related to the implementation of the cognitive prosthetic technology. In the ICP approach, the patient is empowered by the technology and is able to assume a substantial amount of control. The ability to control events is particularly important to managers and professionals, particularly when an injury reduces the control that they are accustomed to. Patients are encouraged to identify their priority activities for rehabilitation. The therapy team is then able to choose among priority activities. The result is that the therapists are working on the patient’s goals. As a result, the patient is more motivated and the level of compliance is very high.

Patients need to participate in the design of their prosthetic software. Working together with specially trained clinicians, patients are able to specify the phrasing of commands and instructions which will be displayed on the computer screen. Also, they learn that they can ask the therapist to rearrange the presentation of information on their computer screens. This kind of customization enables the individual to make their system more “user friendly” for them. This combination helps to collapse the amount of time it takes for the individual to learn how to use the prosthetic software.

The attention to detail is another factor that we believe is critical to achieving our results. This is particularly important in the customization of the prosthetic software as well as the identification of cognitive deficits that need to be bridged. It is important to assure that the interface performs well from beginning to end, and that the individual can perform the target activity. Design problems appear during and after the system is introduced, and those problems needed to be identified and resolved.

From the beginning of our empirical work, we were able to notice anomalies in cognitive dimensions. Cognitive dimensions of profound disability often contained small pockets of abilities. Also, cognitive dimensions with largely intact cognitive performance often had pockets of deficits. The anomalies were visible at the very fine level of granularity which characterizes the detailed stages of software development.

It is significant that many individuals who are successful at clinic-based rehab develop difficulties when performing the target activities in their own environment. Context-specific deficits may be the explanation for this success in one place and failure in another.

This argues for working with the patient in the setting where they will perform their activities. Thus the individual’s home, school, or office is a much more preferable site for delivering rehabilitation services than is the clinic.

Telemedicine enables the delivery of cognitive prosthetic services by a therapist into the home. Coupled with videoconferencing technology, cognitive rehabilitation therapists can work face-to-face with their patients. Therapists are able to give guidance and structure to their remote patients. There are considerable advantages for the patient with this kind of delivery system.

Success at performing an everyday activity often can be subverted by relatively minor deficits. The impact of these minor deficits seems out of proportion to their role in the process; and this is particularly evident in the patient with mild brain injury. Prosthetic software can bridge these deficits. The analysis done by software designers and analysts is well suited for identifying these deficits. It is remarkably easy for us to bridge these deficits and enable successful activity performance.

Out-of-Sequence Rehabilitation

A cognitive prosthesis enables a therapist to address rehabilitation needs out of the sequence normally imposed by the retraining paradigm. This is practical because a cognitive prosthesis can bridge functional deficits. There are a number of instances where this is highly desirable.

For some individuals, especially career-oriented individuals, time is a very significant factor in successfully regaining important aspects of their lives. A prolonged absence from work would require someone else assuming his or her work responsibilities. Often, individuals are able to return to work before many key community-reentry skills had been introduced let alone acquired. However, typically return to work is one of the final stages of rehabilitation, and follows successful completion of a community reentry rehabilitation program. However, this sequence may not become appropriate for career-oriented and high-achiever individuals. There are enough case studies which show job performance relatively unrelated to non-vocational community reentry activities for the career-oriented individual that one has to question the relationship between them.

In an era of managed care restrictions on length of stay, out-of-sequence rehabilitation has many advantages. If rehabilitation is left intentionally incomplete, aspects of rehabilitation can be more attuned to patient priority activities as they develop in the everyday environment. Cognitive prosthetics makes this attainable.

Finally, cognitive prosthetics is able to treat individuals with a range of neurological disorders that cause cognitive deficits in addition to mild brain injury: Traumatic brain injury, stroke, brain aneurysm, anoxia, Parkinson's, and brain cancer.

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REFERENCES

Aftonomos, Lefkos B.; Steele, R.S.; Wertz, R.T. "Promoting Recovery in Cronic Aphasia with an Interactive Technology," *Archives of PM&R,* 78(8), pp.841-46 (1997).

Barlow, David and Hersen, Michael Single-Case Experimental Designs: Strategies for Studying Behavior Change (2nd Ed.), New York, Pergamon Press, 1984.

Brooks, Neil Closed Head Injury, Oxford, Oxford University Press, 1984.

Chute, Douglas L.; Conn, Gretchen; Dipasquale, Madeline C.; and Hoag, Melanie "ProsthesisWare: A New Class of Software Supporting the Activities of Daily Living," In *Neuropsychology*, Vol. 2, pp. 41-57, 1988.

Cole, Elliot. "Cognitive Prosthetics and AssistiveTechnology," Workshop organized and presented at the Brain Injury Association National Symposium, Philadelphia, November 1-4, 1997.

Cole, Elliot "New Treatment Methods for Executive Dysfunction," panel presentation at the Brain Injury Association National Symposium, Philadelphia, November 1-4, 1997.

Cole, Elliot; Dehdashti, Parto; and Yonker, Valerie "Treatment of Plateaued Traumatic Brain Injury Patients by Using Computer-based Cognitive Prosthetics: A Field Study," NIH Neural Prosthesis Workshop, October 15-17, 1997.

Cole, Elliot "Computer-Based Cognitive Prosthetics for the Treatment of Acquired Cognitive Disorders," Second World Congress on Brain Injury, Seville, Spain, May 9-14, 1997.

Cole, Elliot; Matthews Jr., Michael K.; Petti, Linda; and DeStefano, Mary "Tutorial on Computer-Based Cognitive Prosthetics," organized and presented at the Brain Injury Association National Symposium, Dallas, November 1996

Cole, Elliot; DeStefano, Mary; and Petti, Linda "Cost Effective Treatment of Brain Injury," presentation at the Medical Case Management Conference, Orlando, September 1996.

Cole, Elliot; Dehdashti, Parto; Matthews Jr., Michael K.; and Petti, Linda. "Rapid Functional Improvement and Generalization in a Young Stroke Patient following Computer-Based Cognitive Prosthetic Intervention," Presentation at *NIH Neural Prosthesis Workshop*, Bethesda, Maryland, October 19-21, 1994.

Cole, Elliot; Dehdashti, Parto; Petti, Linda; Angert, Marlene "Design and Outcomes of Computer-Based Cognitive Prosthetics for Brain Injury: A Field Study of 3 Subjects," *Neurorehabilitation*, Vol 4, No.3, July 1994.

Cole, Elliot; Dehdashti, Parto; Petti, Linda; Angert, Marlene, and Dray, Susan "Participatory Design with Cognitively Impaired Users: The Insight of Brain Injury Patients Designing Their Prosthetic Software," paper presented at the International Symposium on Human Factors in Organizational Design and Management, Stockholm, Sweden, May 31, 1994.

Cole, Elliot; Dehdashti, Parto; Petti, Linda; Angert, Marlene "Participatory Design for Sensitive Interface Parameters: Contributions of Traumatic Brain Injury Patients to Their Prosthetic Software," CHI '94, *ACM Conference on Human Factors in Computing Systems, Poster Sessions*, Boston, Massachusetts, April 26 & 27, 1994.

Cole, Elliot; Petti, Linda; Matthews, Jr., Michael K.; Dehdashti, Parto "Participatory Design in Computer-Based Cognitive Prosthetics," Presentation at *NIH Neural Prosthesis Workshop*, October 13-15, 1993.

Cole, Elliot; Dehdashti, Parto; Petti, Linda "Implementing Complex Compensatory Strategies for Brain Injury," presentation to the American Congress of

Rehabilitation Medicine 70th Annual Meeting, Denver, Colorado, June 25-27, 1993; abstract published in *Archives of Physical Medicine and Rehabilitation*, 74(6), p. 672, June 1993.

Cole, Elliot; Dehdashti, Parto; Petti, Linda; Angert, Marlene "Computer Software as a Cognitive Orthotic," presented at NIH Workshop on Neural Prosthetics, Bethesda, Maryland, Oct 13-15, 1992.

Cole, Elliot and Dehdashti, Parto "Interface Design as a Prosthesis for Individuals with Brain Injuries," *SIG/CHI Bulletin*, 22(1), pp. 28-32, July, 1990.

Cole, Elliot and Dehdashti, Parto "Increasing Personal Productivity of Adults with Brain Injury Through Interface Design," Presentation at ACM SIG/CHI 88, Washington, D.C., May 1988, (abstract Only) *SIG/CHI Bulletin*, October, 1988.

Cole, Elliot and Bergman, Marilyn "Application of Theory and Methods from Computer Science to the Use of Microcomputers for Community Re-Entry of Closed Head Trauma Clients," (Abstract Only) *Cognitive Rehabilitation* Vol 5(4), p. 29 (July/August 1987), presentation at Cognitive Rehabilitation Conference, Medical College of Virginia, September 1987.

Dowds, Murdo M., "Personal Communication," May, 1997.

Dowds, Murdo M., and Robinson, Kelly "Assistive Technology for Memory Impairment: Palmtop Computers and TBI," Braintree Hospital Traumatic Brain Injury Neurorehabilitation Conference, Cambridge, Massachusetts, September, 28, 1996.

Englebart, Douglas C. "A Conceptual Framework for the Augmentation of Man's Intellect," in *Vistas in Information Handling*, Howerton and Weeds, eds., Washington, DC, Spartan Books, pp. 1-13, 1963.

Freund, Hans-Joachim; Sabel Bernard A.; and Whitte, Otto W. eds., *Advances in Neurology Vol. 73: Brain Plasticity,* Philadelphia, Lippincott-Raven, 1997.

Friedman, Mark and Cole, Elliot "Opportunities for AI in the use of Computer-Based Cognitive Prosthetics," AAAI Fall Workshop on AI for Disabilities, AAAI Press, November 19-23, 1996.

Goodenough-Trepagnier, Cheryl "Visual Analogue Communication: An Avenue of Investigation and Rehabilitation of Severe Aphasia," In *Aphasiology*, Vol. 9, No. 4, pp. 321-341, 1995.

Henry, Kimberly "Personal Communication," November 15, 1989.

Henry, Kimberly; Friedman, Mark; Szekeres, Shirley; Stemmler, Debra "Clinical Evaluation of Prototype Portable Electronic Memory Aid," In *Proceedings of the RESNA 12th Annual Conference*, RESNA '89 pp. 254-255, June 1989.

Hersh, Neil A. and Treadgold, Lawrence G. "NeuroPage: the Rehabilitation of Memory Dysfunction by Prosthetic Memory and Cueing," In *NeuroRehabilitation*, 4(3), pp. 187-197, 1994.

Hoepfer, Maurene, "Computers Help Reporgram Injured Brains," *Pensylvania Medicine*, pp. 34-36, April 1996.

Keen, Peter G.W.; and Scott-Morton, Michael S. *Decision Support Systems: An Organizational Perspective*, Reading, MA, Addison Wesley, 1979.

Kirsch, N.L.; Levine, S.P.; Lajiness, R.; Mossaro, M.; Schneider, M.; Donders, J. "Improving Functional Performance with Computerized Task Guidance Systems," In *Proceedings Compte Rendu International Conference of the Association for the Advancement of Rehabilitation Technology* ICAART 88 pp. 564-56, June 1988.

Kirsch, Ned L.; Levine, Simon, P.; Fallon-Krueger, Maureen; Jaros, Lincoln A. "The Microcomputer as an 'Orthotic' Device for Patients with Cognitive Deficits," In *Journal of Head Trauma Rehabilitation* 2(4) pp. 77-86, 1987.

Levinson, Richard "The Planning and Execution Assistant and Trainer (PEAT)," In *Journal of Head Trauma Rehabilitation*, 12(2), pp. 85-91, 1997.

Matthews, Jr., Michael K. and Cole, Elliot, "Comparison of Independence Training," Presentation at American Neuorpsychiatric Association Annual Conference. Abstract published in *J Neuropsychiatry*, 9(1), p. 155, 1997.

Merzenich, Michael M.; Jenkins, William M.; Johnston, Paul; Schreiner, Christoph; Miller, Steven L.; and Tallal, Paula "Temporal Processing Deficits of Language-Learning Impaired Children Ameliorated by Training," In *Science*, Vol. 271, pp. 77-81, January 5, 1996.

Nudo, R.J.; Milliken, G.W.; Jenkins, W.M.; Merzenich, M.M. "Use-dependent Alterations of Movement Representations in Primary Motor Cortex of Adult Squirrel Monkeys," In *Journal of Neuroscience*, 16(2), pp. 785-807, January 15, 1996.

Parente, Rick "Personal Communication," April 11, 1991.

Scientific Learning Corporation, See WWW.SCILEARN.COM

Steele, Richard D.; Weinrich, Michael; Carlson, Gloria S. "Recipe Preparation By a Severely impaired Aphasic Using the C-VIC 2.0 Interface," In *Proceedings of the RESNA 12th Annual Conference*, RESNA '89 pp. 218-219, June 1989.

Stein, Donald G.; Brailowsky, Simon; and Bruno, Will. *Brain Repair*, New York, Oxford University Press, 1995.

Tallal, Paula; Miller, Steve; Bedi, Gail; Byma, Gary; Wang, Xiaoqin; Nagarajan, Srikantan; Schreiner, Christoph; Jenkins, William; Merzenich, Michael "Language Comprehension in Language-Learning Impaired Children Improved Acoustically modified Speech," In *Science*, Vol. 271, pp. 81-84, January, 5, 1996.

Tallal, P.; Miller, S.L.; Bedi, G.; Byma, G; Jenkins, W.M.; Wang, X.; Nagarajan, S.S.; Merzenich, M.M. "Training with Temporally Modified Speech Results in Dramatic improvements in Speech Perception and Language comprehension," *In Soc. Neuro. Abstr*., Vol. 21, Part I, p. 421, 1995.

Wilson, Barbara A; Evans, Jonathan J.; Emslie, Hazel; Malinek, Vlastimil "Evaluation of NeuroPage: A New Memory Aid," in press.