Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Human Movement Science 22 (2003) 131–135
HUMAN MOVEMENT SCIENCE
www.elsevier.com/locate/humov

Guest editorial

Advances in the study of drawing and handwriting

Ruud G.J. Meulenbroek [a,*], Arend W.A. Van Gemmert [b,1]

[a] *Nijmegen Institute for Cognition and Information, University of Nijmegen, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands*
[b] *Motor Control Laboratory, Department of Kinesiology, Arizona State University, P.O. Box 870404, Tempe, AZ 85287-0404, USA*

1. The study of drawing and handwriting

Since the early 1980s the study of drawing and handwriting movements has come to be known as the field of "graphonomics". The term graphonomics intends to capture the multi-disciplinary scientific effort involved in identifying lawful relationships between the planning and generation of drawing and handwriting movements and in defining the nature and limitations of the processes taking place at various levels of the neuromotor system as these movements evolve. The scientists who delineated the area of graphonomics in 1982 recognized that organizing and promoting research into drawing and handwriting movements was bound to have both scientific and practical benefits. Graphonomic research was not only expected to yield new insights into the specifics of various motor control processes but also to provide a sound basis for technological advancements, which, at the time, were required to meet the growing need to improve and speed up the automatic processing, interpretation and recognition of both static script (for forensic and signature-verification purposes) and digitally recorded pen-tip displacements (for user-friendly and reliable interfaces in hand-held computers).

Advances in graphonomic research have recently been made in several fundamental and applied research areas such as motor control and movement disorders (cf. Thomassen, Keuss, & Van Galen, 1984; Kao, Galen, & Hoosain, 1986; Van Galen, Thomassen, & Wing, 1991; Van Galen & Stelmach, 1993; Faure, Keuss,

* Corresponding author. Tel.: +31-24-3616031; fax: +31-24-3616066.
E-mail addresses: r.meulenbroek@nici.kun.nl (R.G.J. Meulenbroek), vangemmert@asu.edu (A.W.A. Van Gemmert).
[1] Tel.: +1-480-9654718; fax: +1-480-9658108.

0167-9457/03/$ - see front matter
doi:10.1016/S0167-9457(02)00155-0

Lorette, & Vinter, 1994; Simner, Leedham, & Thomassen, 1996; Van Galen & Morasso, 1998), motor development and handwriting education (cf. Wann, Wing, & Søvik, 1991), neuropsychology (cf. Simner, Hulstijn, & Girouard, 2000), biophysics (cf. Van Galen & Morasso, 1998), computer science (cf. Plamondon, Suen, & Simner, 1989; Plamondon & Leedham, 1990; Plamondon, 1993; Singer & Tishby, 1994), and forensic science (cf. Simner et al., 2000; Simner & Girouard, 2000).

The present issue demonstrates advances in graphonomic research in the area of motor control and disorders. It contains five publications that resulted from presentations at the "Tenth Biennial Conference of The International Graphonomics Society", which was held in Nijmegen, The Netherlands, in 2001. Whereas the early studies of drawing and handwriting movements were mostly restricted to analyses of latencies and performance errors as a function of task-complexity variations, this special issue clearly demonstrates that recent research exploits sophisticated analyses of the kinematics, kinetics and dynamics of drawing and handwriting movements. Using these refined analyses the featured studies have the potential to disclose regulating principles involved in redundancy control (Latash et al.), cortical representations of movement parameters (Reina and Schwartz), adaptation (Prager & Contreras-Vidal), cerebellar ataxia (Sanguineti et al.), and position sense (Romero et al.). It could be stated that together the reported studies can shed a new light onto the intriguingly complex processes that take place at multiple levels of the neuromotor system during the performance of basic motor tasks.

The advancement in graphonomic research illustrated by the presently reported studies shares features with the development of computational handwriting models that are capable of simulating drawing and handwriting movements with realistic spatiotemporal and dynamic characteristics. Such models (and their more descriptive precursors), which have been developed since the 1960s, put the growing knowledge, as it emerges, to the test.

2. The development of computational handwriting models

In the 1960s through the early 1980s descriptive information-processing models of handwriting mainly focused on central representations. These models were developed in relative isolation from models that tried to capture the peripheral mechanisms involved in the generation of handwriting movements. Whereas the central, neurocognitive models addressed hierarchical top-down processes, the peripheral, biophysical models emphasized heterarchical and bottom-up processes. Examples of these pioneering analyses of the control of handwriting movements are the neural model of variations in cerebral organization as a function of handedness and writing posture (Levy & Reid, 1987), the neurocognitive models of memory and motor processes involved in spoken and written language (Margolin, 1984; Van Galen & Teulings, 1983; Ellis, 1988) and the first cybernetic model of handwriting movements which, among other aspects, identified the minimum number of independent peripheral mechanisms that are responsible for the quasi-continuous pen-tip displacements that people generate during cursive handwriting production (Denier van der Gon &

Thuring, 1965; Vredenbregt & Koster, 1971). In the late 1980s and 1990s the neurocognitive and biophysical models converged in various ways. Whereas neurocognitive accounts of handwriting yielded computational (neural network) models capable of automatically parsing and recognizing the peripheral stream of digitized pen-tip displacements (e.g., Schomaker, 1992; Wada & Kawato, 1995), biophysical models gradually increased in complexity by describing control mechanisms at more central levels of the neuromotor system (Hollerbach, 1981; Dooijes, 1983; Edelman & Flash, 1987; Bullock, Grossberg, & Mannes, 1993; Morasso & Sanguineti, 1995; Meulenbroek, Rosenbaum, Thomassen, Loukopoulos, & Vaughan, 1996; Plamondon & Privitera, 1996). Researchers from many disciplines contributed to these developments. As a result, recent computational handwriting models address a variety of important motor control issues such as motor equivalence, inverse kinematics, inverse dynamics, optimisation principles, output variability control and perception–action relationships (cf. Flash & Sejnowski, 2001). Although they are not aimed at the development of computational models of handwriting per se, the five studies in the present section of this journal are convincing examples of similar advancements in graphonomic research.

3. The contributions

Latash, Danion, Scholz, Zatsiorsky and Schöner present an overview of their work dealing with the issue of "motor abundancy" in the framework of the uncontrolled manifold (UCM) hypothesis by reviewing experimental evidence pertaining to the coordination of finger forces in isometric force production tasks. This evidence is then used to illustrate the problem of coordinating forces during handwriting. Reina and Schwartz describe how eye and hand movements in primates are coupled during the drawing of curved trajectories. Their work nicely builds on previous work on eye–hand coordination in humans while reaching, aiming and tracking. The experimenters use state-of-the-art technology, not only to record eye and hand movements but also to manipulate visual response-produced feedback. The animal model used in their research has the advantage of allowing the experimenters to take cortical recordings while the monkey was performing the drawing task. The results add significantly to our understanding of eye–hand coordination in primates. Furthermore, it provides new information on the neural basis of the Two-Third Power Law (Viviani & Terzuolo, 1982). Eye movements occurred when tangential hand velocity was minimal, and clustered near regions of high trajectory curvature. Furthermore, saccade onset coincided with maximal curvature in the population-vector trajectory. Prager and Contreras-Vidal try to determine whether direction and amplitude of planned movements are coded independently or interactively. The literature on this issue is still undecided. They report the results of an interesting experiment in which they study – in a pointing task – adaptation to distortions of gain and rotation of planar stylus movements displayed on a computer screen. Using the sequential-adaptation approach, the authors investigate the mechanisms involved in sensorimotor adaptation to visual gain change and visual rotation. They find that the respective adaptation mechanisms are interdependent as evidenced by an anterograde interference of rotation adaptation with gain adaptation. Sanguineti and Morasso present an evaluation of the kinematics of reaching movements in the horizontal plane by subjects with cerebellar ataxia. They show that the first half of the movements of these patients was just as abnormal as the second half of the movement. A cybernetic interpretation of this finding suggests that this phenomenon is likely to be due to a deficit in the internal model of arm dynamics rather than an impairment in involved feedback control mechanisms. Romero, Van Gemmert, Adler, Bekkering and Stelmach, finally, report the results of an experiment that examined the kinematics of pointing movements of young and elderly subjects while manipulating two variables, namely the amount of time that intervenes between getting ready for the movement and the actual go-signal and the availability of vision of the limb and the movement trajectory. Their research tries to capture the role of position sense in movement production.

Acknowledgements

The guest editors thank all contributors to this special issue who made it possible to compile this state-of-the-art sample of current graphonomic research. We also thank Peter Beek and Piet van Wieringen for their work in editing the paper to which the second guest editor contributed. We are grateful to Jos Adam, Otmar Bock, Digby Elliot, Martha Flanders, Stan Gielen, Wouter Hulstijn, Robert Sainburg, Uta Sailer, Marco Santello, Stephan Swinnen and Arnold Thomassen for their reviewing work and their many helpful suggestions for improvement. Finally, we would like to thank the Board of the University of Nijmegen, the Faculty of Social Sciences of the University of Nijmegen and the Royal Netherlands Academy of Arts and Sciences (KNAW) for funding the "Tenth Biennial Conference of the International Graphonomics Society" that took place in 2001 in Nijmegen, The Netherlands. The presentations at this conference formed the basis for this section.

References

Bullock, D., Grossberg, D., & Mannes, C. (1993). A neural network model for cursive script production. *Biological Cybernetics, 70*, 15–28.

Denier van der Gon, J. J., & Thuring, L. Ph. (1965). The guiding of human writing movements. *Kyberntika, 2*, 145–148.

Dooijes, E. H. (1983). Analysis of handwriting signals. *Acta Psychologica, 54*, 99–114.

Edelman, S., & Flash, T. (1987). A model of handwriting. *Biological Cybernetics, 57*, 25–36.

Ellis, A. W. (1988). Normal writing processes and peripheral acquired dysgraphias. *Language and Cognitive Processes, 3*, 99–127.

Faure, C., Keuss, P. J. G., Lorette, G., & Vinter, A. (1994). *Advances in handwriting and drawing: A multidisciplinary approach*. Paris: Europia.

Flash, T., & Sejnowski, T. J. (2001). Computational approaches to motor control. *Current Opinion in Neurobiology, 11*, 655–662.

Hollerbach, J. M. (1981). An oscillation theory of handwriting. *Biological Cybernetics, 39*, 139–156.

Kao, H. S. R., Galen, G. P., & Hoosain, R. (1986). *Graphonomics: Contemporary research in handwriting*. Amsterdam: North-Holland.

Levy, J., & Reid, M. (1987). Variations in cerebral organization as a function of handedness, hand posture in writing, and sex. *Journal of Experimental Psychology: General, 107*, 1719–1744.

Margolin, D. I. (1984). The neuropsychology of writing and spelling: Semantic, phonological, motor, and perceptual processes. *Quarterly Journal of Experimental Psychology, 36*, 459–489.

Meulenbroek, R. G. J., Rosenbaum, D. A., Thomassen, A. J. W. M., Loukopoulos, L. D., & Vaughan, J. (1996). Adaptation of a reaching model to handwriting: How different effectors can produce the same written output, and other results. *Psychological Research, 59*, 64–74.

Morasso, P., & Sanguineti, V. (1995). Self-organizing body scheme for motor planning. *Journal of Motor Behavior, 27*, 52–66.

Schomaker, L. R. B. (1992). A neural oscillator-network model of temporal pattern generation. *Human Movement Science, 11*, 181–192.

Plamondon, R. (1993). Handwriting processing and recognition. *Pattern Recognition, 26*, 379–460.

Plamondon, R., & Leedham, C. G. (1990). *Computer processing of handwriting*. Singapore: World Scientific.

Plamondon, R., & Privitera, C. M. (1996). A neural model for generating and learning a rapid movement sequence. *Biological Cybernetics, 74*(1), 117–130.

Plamondon, R., Suen, C. Y, & Simner, M. L. (1989). *Computer recognition and human production of handwriting*. Singapore: World Scientific.

Simner, M., & Girouard, P. (2000). Advances in forensic document examination: Selected papers from the ninth biennial conference of the International Graphonomics Society. *Journal of Forensic Document Examination, 13* (Special Issue).

Simner, M., Hulstijn, W., & Girouard, P. (2000). Advances in Forensic Document Examination: Selected Paper from the Ninth Biennial Conference of the International Graphonomics Society. *Journal of Forensic Document Examination, 13*, Special Issue 1–109.

Simner, M. L., Leedham, C. G., & Thomassen, A. J. W. M. (1996). *Handwriting and drawing research: Basic and applied issues*. Amsterdam: IOS Press.

Singer, Y., & Tishby, N. (1994). Dynamical encoding of cursive handwriting. *Biological Cybernetics, 71*, 227–237.

Thomassen, A. J. W. M., Keuss, P. J. G., & Van Galen, G. P. (1984). *Motor aspects of handwriting: Approaches to movement in graphic behavior*. Amsterdam: North-Holland.

Van Galen, G. P., & Morasso, P. (1998). Neuromotor Control in Handwriting and Drawing. *Acta Psychologica, 100* (1/2).

Van Galen, G. P., & Stelmach, G. E. (1993). Handwriting: Issues of psychomotor control and cognitive models. *Acta Psychologica, 100* (Special Volume).

Van Galen, G. P., & Teulings, -L. (1983). The independent monitoring of form and scale factors in handwriting. *Acta Psychologica, 54*, 9–22.

Van Galen, G. P., Thomassen, A. J. W. M., & Wing, A. M. (1991). Handwriting. *Human Movement Science 10*, Special issue 1–349.

Viviani, P., & Terzuolo, C. (1982). Trajectory determines movement dynamics. *Neuroscience, 7*, 431–437.

Vredenbregt, J., & Koster, W. (1971). Analysis and synthesis of handwriting. *Philips Technical Review, 32*, 73–78.

Wada, Y., & Kawato, M. (1995). A theory of cursive handwriting based on the minimization principle. *Biological Cybernetics, 73*, 3–13.

Wann, J., Wing, A. M., & Søvik, N. (1991). *Development of graphic skills: Research, Perspectives and educational implications*. London: Academic Press.