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Human Movement Science 25 (2006) 447–453
HUMAN MOVEMENT SCIENCE
www.elsevier.com/locate/humov

Advances in graphonomics: Studies on fine motor control, its development and disorders

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Abstract

During the past 20 years graphonomic research has become a major contributor to the understanding of human movement science. Graphonomic research investigates the relationship between the planning and generation of fine motor tasks, in particular, handwriting and drawing. Scientists in this field are at the forefront of using new paradigms to investigate human movement. The 16 articles in this special issue of Human Movement Science show that the field of graphonomics makes an important contribution to the understanding of fine motor control, motor development, and movement disorders. Topics discussed include writer's cramp, multiple sclerosis, Parkinson's disease, schizophrenia, drug-induced parkinsonism, dopamine depletion, dysgraphia, motor development, developmental coordination disorder, caffeine, alertness, arousal, sleep deprivation, visual feedback transformation and suppression, eye–hand coordination, pen grip, pen pressure, movement fluency, bimanual interference, dominant versus non-dominant hand, tracing, freehand drawing, spiral drawing, reading, typewriting, and automatic segmentation.

PsycINFO classification: 2330; 2221

Keywords: Hand; Motor control; Motor development; Movement disorders

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doi:10.1016/j.humov.2006.07.002

1. Handwriting, drawing, and fine motor control

In 1982, a relatively small group of scientists from several disciplines, who were interested in the mechanisms involved in the production of handwriting, decided to have a workshop on motor aspects of handwriting at the University of Nijmegen (Radboud University), The Netherlands. This workshop formed the very first scientific meeting in 20 years since the Invitational Conference on Research in Handwriting, University of Wisconsin – Madison, USA (Herrick, 1963). The workshop in Nijmegen was pivotal for the formation of a society for the advancement of handwriting research. The domain of 'graphonomics' was defined and this set the stage for the foundation of the International Graphonomics Society as we know it today (IGS, 1987). At this workshop in 1982, graphonomics was presented for the first time as a concept denoting the scientific and technological efforts involved in identifying relationships between the planning and the generation of handwriting and drawing movements, resulting in visible traces on paper (or on electronic media with electronic pens), and the dynamic characteristics of these fine motor movements (see www.cedar.buffalo.edu/igs/ or www.graphonomics.org/igs2007).

The 2005 conference was the 12th international conference under the auspices of the International Graphonomics Society (IGS) and the 13th is upcoming (IGS2007). All conferences have been successful in attracting many researchers from diverse areas, ranging from fundamental to applied research, such as motor control, motor learning and education, motor development and aging, movement disorders, neuropsychology, biophysics, forensic science, paleography, computer science, cognitive science, pattern recognition, and artificial intelligence. The past biennial conferences of the International Graphonomic Society (IGS) resulted in many special journal issues and books which exemplify the multitude of interests of researchers in the field of graphonomics (cf. Faure, Keuss, Lorette, & Vinter, 1994; Kao, Van Galen, & Hoosain, 1986; Meulenbroek & Van Gemmert, 2003; Plamondon, 1993; Plamondon, Suen, & Simner, 1989; Plamondon & Leedham, 1990; Simner & Girouard, 2000; Simner, Hulstijn, & Girouard, 1994; Simner, Leedham, & Thomassen, 1996; Teulings & Van Gemmert, 2004; Teulings, Van Gemmert, & Girouard, 2004; Thomassen, Keuss, Van Galen, & Grootveld, 1983; Van Galen & Morasso, 1998; Van Galen & Stelmach, 1993; Van Galen, Thomassen, & Wing, 1991; Van Gemmert & Teulings, 2004; Wann, Wing, & Søvik, 1991).

Since 2001 the influence of multi-disciplinary collaborations and technical advancements has further expanded the paradigms in graphonomics (e.g., eye-movements, finger/grip control, etc.). This expansion of paradigms and their multi-disciplinary nature have pushed graphonomic research into the center of motor control. This special issue of Human Movement Science on graphonomic research provides important contributions to the understanding of fine motor control, its specific development, and its specific disorders. Extrapolation of this trend could mean that fine motor control not only has its own neurological substrate but could also become a distinguishable domain next to total-body movement research.

2. The contributions

The first five contributions focus on *motor disorders* and may have consequences for the efficiency to perform handwriting and/or drawing movements. Many movement disorders are accompanied by attentional deficiencies either due to the disease or as a result of the additional effort to compensate the movement disorder. For example, it is often suggested that patients confronted with a deteriorated motor system increasingly use visual feedback to reduce erroneous movement outcomes. Closely monitoring movements and integrating these into the planning of consecutive segments of the movement require attentional resources so that a limited amount of resources will remain available to deal with other demands of the task. Therefore, the interplay between *attention, arousal, and/or vision in fine motor tasks* deserves more cognizance as we show in the second group of five contributions. Furthermore, *modeling and automatic recognition* will support the development of tools which could help scientists and physicians in the future to better assess movement disorders, and/or developmental abnormalities. The final group of five contributions shows that there is an abundance of questions on *developmental aspects of fine movement control* in relation to the effects of visual feedback, the allocation of attentional resources, and motor learning.

2.1. Movement disorders

In the first contribution, *Hallett* presents an overview of the pathophysiology of *writer's cramp* and its therapeutic implications. He particularly focuses on three possibilities, i.e., loss of inhibition, abnormal plasticity of the motor cortex, and sensory dysfunction. In the second contribution, *Baur and colleagues* show that if patients suffering from writer's cramp modify their *pen-grip* from a conventional dynamic tripod grip to a tripod grip in which the shaft of the pen is held between the index and middle finger, they will reduce the writing pressure and the excessive forces normally found in writer's cramp patients. The modified pen grip increases also the finger surface in contact with the pen and therefore distributes the grip forces that stabilize the grip and dynamically drive the tip of the pen. Both of these effects of the modified pen grip are beneficial to writer's cramp patients because they may have difficulty separating sensory inputs to stabilize the pen and to drive the pen movement. These patients have difficulties when using a conventional dynamic tripod pen grip possibly because the same fingers receive the sensory inputs due to the grip and the movement. They will benefit from the modified pen grip as separate fingers will then receive those sensory inputs. Future research could confirm whether the alternative grip suggested by Baur and colleagues will result in a reduced activation of the sensory cortex as suggested by Hallett.

Many neurologists are using *spiral drawing* as one of the tools to assess severity of the motor disorder in patients suffering from diseases that affect motor control. *Longstaff and Heath* show that patients suffering from *multiple sclerosis* drew spirals with more variability around an ideal trajectory. Interestingly, increased variability in the patients was accompanied by lower *penpressures*. The finding that patients show either higher or lower levels of pen pressure than controls (see Baur et al., and Longstaff and Heath, respectively), suggests that an optimal pen pressure exists for normal handwriting movements. Future research may establish which pen pressure levels may be considered as abnormal and therefore may indicate a movement disorder.

The next contribution by *Lange and colleagues* features three experiments, which show how *handwriting fluency* could be affected by *dopamine depletion*. All three experiments revealed that the number of velocity inversions increases if the assumed dopamine levels are lowered either by disease or experimental manipulation. Lange and colleagues argue that the dopamine depletion reduces the automation of the handwriting movements resulting in an increase of the number of inversions. Although not all scientists agree whether dopamine levels in the brain were significantly decreased in Experiments II and III as both techniques used are still new, the experiments demonstrate that these techniques result in effects similar to those observed in Parkinson's disease patients. This study illustrates how researchers in the field of graphonomics use innovative paradigms to investigate fine motor control. Also *Caligiuri and colleagues* used a novel experimental design. They compared handwriting kinematics of patients suffering from *Parkinson's disease* and patients suffering from *schizophrenia* who show *drug-induced parkinsonism*. Whereas Lange and colleagues used the number of velocity inversions to estimate the smoothness of the movement, Caligiuri and colleagues used normalized jerk. The latter study showed that smoothness was a distinguishing factor between drug-induced parkinsonism in schizophrenia patients and Parkinson's disease patients.

2.2. Attention, arousal, vision, and fine motor control

In the sixth contribution of this special issue, *Tucha and colleagues* describe the effects of *caffeine* on fine motor control. It is shown that relatively high doses of caffeine increase the speed and smoothness of handwriting movements. In the past, caffeine has been suggested to alter *alertness and arousal*. Therefore, the next study by the same research group (*Tucha et al.*), which investigates the effects of attention and alertness on handwriting, complements the previous study. The first experiment in this study showed that attention might be unrelated to performance in highly skilled motor tasks such as handwriting. Their second experiment showed that alertness was deteriorated after *sleep deprivation*; however, handwriting performance did not deteriorate as exemplified by higher speed, increased smoothness, while legibility or accuracy were not affected. These two contributions show that changes in alertness and/or attention may be independent of changes in the execution of skilled movement tasks. This result supports the classical notion that automatic movement control reduces the need for attentional resources. The classical view on performance of skilled motor tasks suggests also that the need for visual feedback is reduced when movement control becomes more automatic.

In motor control, visual feedback has been an important topic of study since Woodworth (1899) investigated the relation between vision, accuracy, and speed (using pen and paper tests!). *Bo and colleagues* are interested in how *children* of different age-groups deal with *transformations of visual feedback*. They show that transformations of visual feedback on the vertical computer display of movements performed in the horizontal plane (as common as computer-mouse movements) do not alter the movements in adults, while children younger than 8 years appear very much affected by this common transformation. This result should have consequences for the use of the mouse as a pointing device in computer-operated tests in young children. Future research should also address how attentional demands are changing when visual feedback is transformed. It is possible that the limited attentional resources in children younger than 8 years dramatically reduce their proficiency in these transformation tasks.

Tracing drawing patterns requires more visually guided movements than freehand drawing. *Gowen and Miall* are one of the first to explore how *hand- and eye-movements* interact in *tracing and freehand drawing*. As expected, they found that hand and eye movements are much more closely coupled in tracing than in freehand drawing. This study is exciting, because their experimental setup could be used to investigate if (and how) individuals with a movement disorder increase or decrease the coupling between hand and eye movements.

2.3. Models and recognition

The diversity of disciplines involved in research into the execution of handwriting makes it sometimes difficult to find a common denominator between scientists. *Plamondon and Djioua* show that their *Kinematic Theory of Rapid Human Movements* can facilitate this process by providing a model, which can be useful for researchers on the cusp of handwriting recognition, and motor control issues of handwriting. *Rosenblum and colleagues* demonstrate how automatic recognition might be used to study motor control issues. They used a relatively simple *automatic segmentation* procedure based on *pressure exertion* of the pen and showed that the features they derived, could distinguish *dysgraphic* from *proficient writers*. Future studies could improve by detailed stroke processing technique using movement generation models as suggested in Plamondon and Djioua. This may result in a larger number of distinguishing features between healthy and impaired handwriting, which ultimately will expand the applicability of graphic tablets as a tool in *movement-disorder diagnosis*.

2.4. Aspects of development of fine motor control

The 12th contribution, by *Kagerer and colleagues*, investigates how children with a *developmental coordination disorder (DCD)* adapt to *rotation of visual feedback*. They found that children with DCD who perform a large number of trials (126) in which they learn to transform a gradually increasing rotation of the visual feedback did not show *aftereffects* when the rotation was removed. In contrast, normally developing children did show a substantial aftereffect. The authors suggested that the DCD children do not update their internal representation but use continuous visual control during acquisition without learning. The contribution by *Contreras-Vidal*, from the same research group, uses a similar task. However, the *visual feedback is suppressed*. He found that when visual feed back was suppressed after a practice session of 40 trials with visual feedback, children younger than 7 years performed less accurate movements than adults. This suggests that the adults had achieved automatization. It would be interesting to see whether children would simply require more trials to automatize the movement as implied by the results of Kagerer and colleagues. It would also be interesting to determine whether children with DCD are more sensitive to suppression of visual feedback than their 'healthy' peers.

In all *educational settings*, from elementary school to university, students are increasingly using keyboards to compose texts. It has not been tested to what extent the increasing use of keyboards affects the development of reading skills. *Longcamp and colleagues* investigated whether *handwriting or typing* is superior in facilitating the learning to *recognize and read new letters*. Their results suggest that handwriting facilitates storage of newly learned characters in long-term memory. Future research should determine what the consequences will be for the use of computers in the curriculum in primary school children.

The last two contributions of this issue investigate developmental aspects of hand-dominance. Whereas the contribution by *Van Mier* investigates the differences in development between the *dominant and non-dominant hand* in fine motor control, the contribution of *Otte and Van Mier* investigates the *interference* between the two hands in a *bimanual task*.

The latter contribution showed that *children between the ages of 4 and 11* were able to coordinate simultaneously different tasks with each hand. This study shows also that the reduction in performance in bimanual tasks compared to unimanual tasks is relatively similar between the 4- and 11-year olds, suggesting that bimanual control has already developed at the fourth year. Nevertheless, Van Mier's study shows that end-point accuracy demands in the non-dominant hand are still not fully matured in 10-year olds. The question remains whether development of bimanual control follows the development of the non-dominant hand control.

In summary, all these contributions illustrate the diversity of the field of graphonomics and prove that the researchers in this field are leading by introducing new paradigms. We hope that readers of this special issue will attend the IGS2007 conference in Melbourne, Australia.

Acknowledgements

The guest editors thank all contributors to this special issue. Their contributions made it possible to show what current research in graphonomics has to offer to the understanding of mechanisms underlying fine motor control in humans. We thank the organizers of IGS2005, Angelo Marcelli and Claudio De Stefano, because without their hard work organizing the 12th IGS conference we would not have had such a large number of high quality contributions for this issue. We are also grateful to Peter Beek for his editorial work on the paper to which the second guest editor contributed, and for his general editorial assistance. Finally, we are especially thankful to the many reviewers who made critical and valuable comments and suggestions that helped to improve the papers.

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