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Graphonomics: The study of handwriting and drawing skills to understand motor behavior and learning across the life span

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1. Introduction

More than 35 years ago the term 'graphonomics' was used for the first time (Van Gemmert & Teulings, 2004) to denote multidisciplinary research focused on motor control aspects of handwriting and drawing skills. Over the years it has been questioned whether graphic skills had a future since technological advances provided attractive alternatives (see also Phillips & Van Gemmert, 2009; Van Gemmert & Contreras-Vidal, 2015). In the past, arguments have been made that future advances would require the use of graphic movements to interact with new devices (keynote speech of the late Professor Arnold Thomassen referenced in Phillips & Van Gemmert, 2009); such devices have indeed become a reality today (e.g., Samsung Galaxy Note 9 smartphone, LG Stylo 3 smartphone, Chuwi Hi12 Stylus tablet, ASUS ZenPad Z10 tablet, signature pads, etc.). Several recent studies suggest that handwriting and reading skills are intimately related indicating that handwriting facilitates reading acquisition (Longcamp, Richards, Velay, & Berninger, 2016; James & Engelhardt, 2012; Kiefer et al., 2015). Furthermore, in recent years some educators have argued that the use of handwriting to take notes should be stimulated instead of using keyboard-enabled devices like laptops and PCs. This viewpoint was supported by a recent study showing that taking handwritten notes resulted in better retention of information than taking notes using a laptop (Mueller & Oppenheimer, 2014).

Graphonomics has contributed considerably to generating theoretical insights into motor behavior in general (Van Gemmert & Contreras-Vidal, 2015). The current special issue of Human Movement Science reflects the long standing collaboration between the journal and the International Graphonomics Society (IGS) to showcase the value of motor behavior research within the field of graphonomics (Van Galen, Thomassen, & Wing, 1991; Meulenbroek & Van Gemmert, 2003; Phillips & Van Gemmert, 2009; Vinter, Van Gemmert, & Phillips, 2011; Contreras-Vidal, Vinter, & Rogers, 2013; Van Gemmert & Contreras-Vidal, 2015). Whereas in the past most authors were members of the IGS, this is no longer the case for the present issue, even though all studies are of course devoted to graphonomics.

2. Three overarching themes

The 12 papers in the present special issue can be divided in three overarching and partially overlapping themes. The first theme refers to the developmental aspects of handwriting. This theme is addressed in the first six papers. The second theme focuses on movement function of individuals with neurological disorders. This theme is addressed in five papers, including papers 5 and 6, which also refer to development, and papers 7, 8 and 9 addressing movement control of older adults with neurological disorders. The final theme includes the last three papers, numbered 10, 11 and 12, and refers to the relationships between sensory input and fine movement output.

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3. Developmental aspects of handwriting and graphic control

Hess, Mousikou, Verrel, and Schroeder are interested in syllabic processing of children producing handwritten text. Although some research on handwriting using Romance languages indicated that syllables are used to generate handwritten text, previous research on the production of handwriting in German has been equivocal in this respect. *Hess et al. (this issue)* suggest that this may be due to the fact that syllabic ambiguity is more common in German than in Romance languages. This ambiguity creates a conflict that needs to be resolved before the syllables can be used to produce handwritten text. These findings and their interpretation may improve current models of handwritten language production.

Whereas the study by Hess et al. focuses on handwritten text, *Séraphin-Thibon, Barbier, Vilain, Sawallis, Gerber, and Kandel* concentrate on the challenges induced by the complexity of handwritten letters. They show that the acquisition of written letters can be divided into two phases. In the first phase, children learn to improve the actual writing of the letter resulting in duration reduction, while in the second phase children learn to automate writing letters resulting in dysfluency reduction. They further show that letters requiring rotation movements exhibited different improvements than letters requiring aiming movements due to pen-lifts needed to anchor strokes during the first phase. The letters requiring rotation movements exhibited a reduction in the difference between maximal and minimal velocity as compared to control letters (i.e. letters that do not require rotation movements). Thus, the fluctuation of velocity was reduced making the movements more stable allowing for more efficient movement control to produce curvature. The letters requiring lift-ups for anchoring of strokes showed a different trade-off – the time of the pen on the surface decreased at the expense of an increase of time in the air. This pattern may suggest that the child learns to keep the writing tempo of the letter the same. These improvements occur in the first phase of learning while in the second phase children learn to automate writing letters. To understand the occurrence of the differences between letters with curvature and aiming movements, and its significance in the learning process for the next phase when automation occurs, additional research is needed.

Guilbert, Alamargot, and Morin expand the findings of Séraphin-Thibon et al. (this issue) by investigating the role of visual and proprioceptive feedback in the development of handwriting on a tablet screen. As expected, the need for visual feedback decreased with practice. Children in the early stages of learning to write were affected much more by the omission of visual feedback than more experienced children and adults. Interestingly, the authors also manipulated friction in an attempt to disentangle the contributions of visual and proprioceptive feedback. In all age groups this manipulation had much less impact than visual manipulation. However, the effects seemed most pronounced in older, more experienced, children who may just have acquired the capability to plan entire letters and words. This study shows that the acquisition of motor skills relies on multiple feedback sources that need to be integrated within the sequence planning and goal of the action.

Whereas the previous three studies used some inventive manipulations to investigate the processes involved when children learn handwriting, *Bingham and Snapps-Childs'* study aims at using such knowledge to develop a training protocol to improve manual control of styli during drawing movements. The proposed protocol holds promise for helping typically developing children as well as children with developmental coordination disorder to improve the manual control which is necessary to efficiently use a stylus when producing graphic movements.

The fifth paper by *Galli, Cimolin, De Pandis, Ancillao, Condoluci, and Stella* focuses both on typically developing children and children with dyslexia or dysgraphia. Whereas dysgraphia is referred to as a learning disability affecting the performance of handwriting and other fine motor tasks, dyslexia is commonly defined as a language-based impairment. However, in agreement with previous reports, the current study shows that dyslexia may also be related to impaired fine motor control. The authors present evidence that movement planning in children with dyslexia is affected, resulting in reduced accuracy levels. The implications of these findings for handwriting training need to be elucidated in future research.

The contribution of *Duda, Casey, O'Brien, Frost, and Phillips* also addresses fine motor behavior challenges as a result of disability. In this case, the emphasis is on children and adults with Attention-Deficit/Hyperactivity Disorder (ADHD). Many reports have shown that handwriting of children with ADHD is often illegible and much less organized than handwriting of age-matched peers without ADHD. It has been suggested that individuals with ADHD have difficulties with procedural learning and skill automation. Contrary to individuals without ADHD the production of novel graphemes seemed not to become automated in individuals with ADHD, despite training. This finding reinforces the view that more research is required to determine optimal protocols to teach fine motor skills, such as handwriting, in different populations.

4. Aging, neurological disorders, and graphic control

The next three contributions concentrate on older adults experiencing challenges due to neurological disorders. *Yu and Chang's* study aims to explore whether graphic movements captured on a digitizer tablet can be used to assess cognitive dysfunction in individuals with Alzheimer's disease (AD) and amnestic mild cognitive impairment (aMCI). Their findings suggest that individuals with AD and aMCI have difficulties in making accurate and fluent movements, especially when incompatible movements of wrist and fingers are required, i.e. when flexing of the wrist needs to be accompanied by extension of the fingers and vice versa. This finding indicates that fine motor function is affected in the early stages of dementia and thus graphic task performance may facilitate early detection of cognitive impairments.

The study of *Danna, Velay, Eusebio, Véron-Delor, Witjas, Azulay, and Pinto* centers around Parkinson's disease (PD). They used the common spiral drawing task to assess whether pen movement characteristics collected with a digitizer tablet in individuals with PD could be used to detect movement control changes due to medication and/or the laterality of PD symptoms in relation to hand dominance. The findings indicated that medication improves movement fluency and that this effect was most pronounced for the hand at the most affected body side. These findings suggest that analyzing graphic movements using a digitizer tablet may be useful for the diagnosis and treatment of individuals with PD.

The study by Senatore and Marcelli also deal with individuals with Parkinson's disease. They tested the hypothesis that movements in these patients are hampered by an inability to fine tune movement plans due to problems in incorporating relevant parameters. On the basis of this hypothesis they predicted that the motor performance of individuals with PD would be similar to the performance of healthy individuals who had not yet mastered the motor task in question. That prediction was borne out, thus supporting the view that PD hampers movement automation and shedding light on the role of the basal ganglia in the acquisition of fine motor skills.

5. Understanding fine motor function using graphic tasks

The last three contributions to this special issue are devoted to motor behavior in healthy individuals. In these studies participants were required to move a stylus across a digitizer tablet.

The study by Lei, Akbar, and Wang focuses on transfer effects to disentangle direct and after-effects of the adaptation to a velocity dependent force field. They argued that training could lead to the formation of an internal model, and if so, this model should lead to after-effects. Their experimental results showed significant intra limb transfer of both direct and after-effects, whereas inter limb transfer was observed for direct effects, but not for after-effects. These findings suggest that indeed an internal model was formed encompassing both effector-dependent and effector-independent neural representations.

Pan and Van Gemmert concentrate on the spatial control during bimanual tasks. Whereas the temporal control of bimanual coordination has received much attention, information about spatial control during bimanual coordination tasks is sparse. This study was dedicated to amplitude and direction control during such tasks. Its findings suggest that amplitude control is more demanding than direction control when performing a bimanual task. The study in question represents a first step to a more comprehensive model of spatial control during fine motor tasks, albeit that the suggestion that amplitude and direction control are affected differently by resource demands needs further confirmation. The final contribution, by Oh, Braun, Reggia, and Gentili, aims at understanding the neural mechanisms and computations involved in visuospatial transformations, which are needed when imitating movements performed by a model during training. The researchers developed internal models based on neuroanatomical and neurophysiological knowledge of brain structures, including the mirror system. Although their model, which includes the role of the mirror neuron system, accounts for the fact that action imitation may occur independently of the observer's viewpoint, it is still confined to two-dimensional movements and should be further tested with regard to three-dimensional movements. In the long run this study might be viewed as a first step in the development of human-robot applications.

6. Conclusion

In conclusion, this special issue testifies to the importance of a multidisciplinary approach to handwriting, as championed by the International Graphonomics Society, to the furthering of knowledge about motor behavior and learning across the life span.

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