Les Cahiers du GERAD ISSN: 0711–2440

An Algorithm for Qualifying Eye Movements During Handwriting

D. Alamargot, G. Caporossi,
D. Chesnet

G–2011–41

August 2011

An Algorithm for Qualifying Eye Movements During Handwriting

Denis Alamargot

CeRCA, Université de Poitiers
99, avenue du Recteur Pineau
86000 Poitiers, France
denis.alamargot@univ-poitiers.fr

Gilles Caporossi

GERAD & HEC Montréal
3000, chemin de la Côte-Sainte-Catherine
Montréal (Québec) Canada, H3T 2A7
gilles.caporossi@hec.ca

David Chesnet

CeRCA, Université de Poitiers
99, avenue du Recteur Pineau B.P. 632
86022 Poitiers, France
david.chesnet@univ-poitiers.fr

August 2011

Les Cahiers du GERAD

G–2011–41

Abstract

The decomposition of the movement of the eye into different categories is critical to their study. According to the algorithm used, some movements may significantly be over or under estimated. The two most important movements (saccade, swift movement and fixation, when the eye remains on the same position to capture information) are well characterized and usually properly identified by most algorithms, however in the context of writing, some other movements cannot be characterized as fixations or saccades. These movements may either be considered as microsaccades or slow movements which are actually close to saccades of fixations respectively but without completely sharing their characteristics. None of the algorithms available for eye movements classification can handle all the four movements. Some of them tend to first identify fixations by the barycenter method while others first identify saccades by the mean of speed. The approach used here is different as movements are first decomposed into elementary movements according to the acceleration scheme before they are merged. This new approach allows a better identification of each of the 4 kinds of movements.

Résumé

Lorsqu'on étudie les mouvements oculaires, la décomposition du mouvement de l'œil en différentes catégories est primordiale. Selon l'algorithme utilisé, certains mouvements peuvent être sur-estimés ou sous-estimés. Les deux mouvements les plus importants (la saccade, un mouvement rapide, et la fixation, alors que l'œil reste à la même position pour saisir de l'information) sont bien définis et généralement correctement identifiés par la plupart des algorithmes; toutefois, dans un contexte d'écriture, certains mouvements ne peuvent pas être considérés comme saccade ou fixation. Ces mouvements peuvent être considérés comme microsaccades ou mouvements lents, les premiers étant assez proches des saccades et les seconds des fixations, même s'ils n'en partagent pas toutes les caractéristiques. Aucun des algorithmes disponibles ne permet une identification de ces quatre mouvements. Certains d'entre eux identifient d'abord les fixations par une méthode utilisant les barycentres alors que d'autres reconnaissent d'abord les saccades en se basant sur la vitesse. L'approche utilisée ici est différente puisque les mouvements sont d'abord décomposés en mouvements élémentaires en se basant sur le schéma d'accélération avant de les regrouper. Cette approche permet une meilleure identification de chacun des quatre mouvements.

Introduction

The goal of this paper is to present an algorithm for qualifying eye movements during handwriting. As stated by Alamargot, Chesnet, Dansac and Ros (2006), using eye movements recorded while writing requires further study of their meaning and their validity as indicators of writing processing. Although widely studied for reading studies, eye movement parameters such as saccades, fixations and gazes may be easily adapted to research on writing. In particular, backward saccades and regressive fixations while writing (returning to the trace produced so far) could be considered as clues to information selection as they are in reading or scene perception tasks. In this case, the durations of regressive fixations would be similar to those measured in classical reading or information searching studies (Rayner, 1998). This behaviour (backward-regressive saccades and fixations) has been already targeted in studies about subject-verb agreement during the writing production of a sentence (see Alamargot et al., in press).

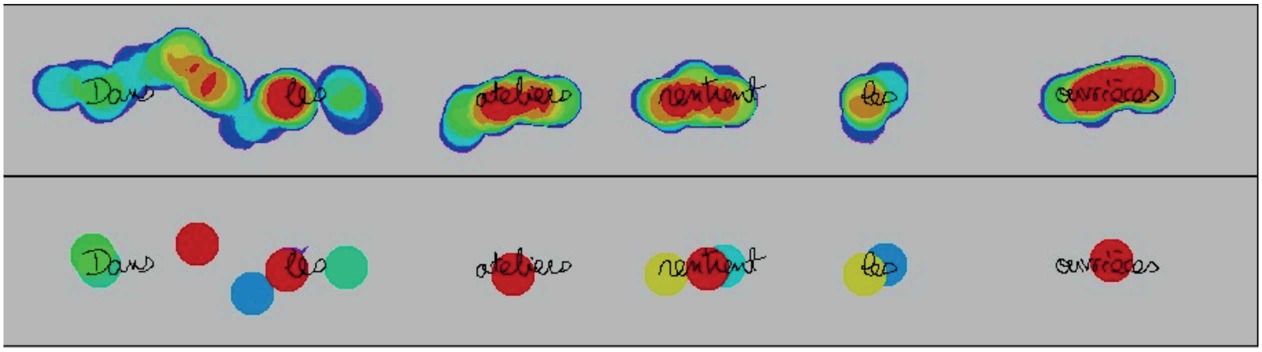
However, as observed by Caporossi, Alamargot, and Chesnet (2004), the context involved in graphic production, and actually in handwriting, can cause specific eye behaviour that remains to be studied. When handwriting is ongoing, it is frequent that the eye "follows" the slow motion of the pen tip (6 to 10 degrees/sec). Two types of followings seems to occur, apparently depending on the pen's speed and that the eye is closed to the pen. (i) The first is a continuous slow movement, looking like an eye pursuit. Gowen and Miall (2006) already showed such a kind of slow movements in drawing and tracing tasks, by considering the target (here the pen) speed thresholds usually accepted to identify a smooth pursuit (from $5.35\,^{\circ}$/s to $31.8\,^{\circ}$/s, with a minimum duration of 75 ms). (ii) The second type of following is not continue, as in the case of pursuit, but discrete. While the pen is moving, the eye remains stationary, making a fixation (the distance to the moving pen increases then) and then moves rapidly to the pen, making a short translation to the pen. This behavior looks like microsaccadic movements to reposition the eye but with a limited amplitude, so that large speed is not observed as in saccades. Miall, Imamizu et Miyauchi (2000) already described such a kind of microsaccades during handwriting.

The question of the role of these two eye behaviours during handwriting, and their relationships if any, remains relatively unanswered and several hypotheses can me made. Gowen and Miall's results (2006) shows that pen pursuits are more frequent when the task's cognitive cost is low (tracing compared to drawing). From a graphomotor standpoint, it can be assumed then that during a pursuit, the eye simply controls the topokinetics characteristics of the written trace (i.e. the spatial disposition of the message – words spacing, lines changing, horizontality, etc.) and, in youngest children who have yet automatized the graphomotor programm, the morphokinetics of the letter (form of letters – Chartrel and Vinter, 2006). From a psycholinguistic and cognitive standpoint, another hypothesis is that while the eye is following the pen, it also supervises the unit being produced, in order to detect and revise immediatly an error, at executing and/or orthographical levels. The on-line analysis could suppose a longer examination of the units, leading to a series of short and closed fixations, separated by microsaccades. Nevertheless, if we admit that eye movements during writing are composed by 4 different behaviours like fixations, saccades, slow movements and microsaccades, then the matter is to establish, as a very first step, a classification of the four parameters within a same calculation.

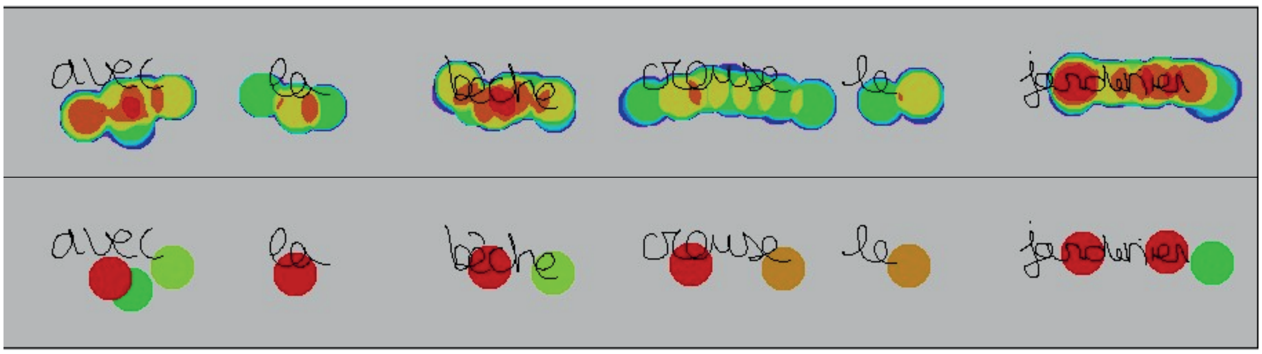
Using classical fixations or saccades calculation algorithms based on distance, speed and/or acceleration criteria leads to an overestimation of the durations of fixations and inaccurately identifies their barycenter. This phenomenon is illustrated in the Figure 1.

In a pilot study, we asked adults participants to recall by handwriting a series of dictated sentences. The eye movements and the graphomotor activity were recorded using the *Eye and Pen*© software (Alamargot, Chesnet, Dansac and Ros, 2006; Chesnet and Alamargot, 2005). The visualization of the eye cinematics, by using a temperature representation, shows that an algorithm usually used in reading research for agregating fixations (here barcenter method) clearly underestimate the locations were the eye gazed. Indeed, a sequence of successive, short and relatively stationary fixations can be interpreted as being a unique fixation. This is here the case of four words "ateliers", "ouvrières" (Figure 1(a)), "creuse", "jardinier" (Figure 1(b)).

Indeed, the algorithms considered for reading studies are obviously specialized in the detection of saccades and/or categorization of fixations, while the study of slow and continuous movements (like smooth pursuit) and/or rapid ans short movements (like microsaccades) remain in very separate fields, with specific criteria, mostly dedicated to eye-hand coordination for the first and/or perceptual mechanisms for the second.



(a) Written recall of the sentence: “Dans les ateliers rentrent les ouvrières” (In the workshops the workers return) – participant 103.



(b) Written recall of the sentence: “Avec la bêche creuse le jardinier” (With the spade digs the gardener) – participant 204.

Figure 1: Comparison of eye movements cinematic without fixation aggregation (up) and with fixation aggregation using a barycenter algorithm (down). The temperature representation (from cold to warm colors) indicates the location of eye and time spent on this location.

Nevertheless, the composite nature of the handwriting activity, engaging eye-hand coordination as well as reading behavior, leads to complete the classical algorithm elaborated in reading research (fixations and saccades) in order to integrate the calculation of complementary parameters susceptible to fully describe the activity. This is the objective of the algorithm in this paper.

Caracterization of the different eye movements

Before describing the algorithm, we here give the caracteristics of the different eye movements we are willing to identify. If the exact parameters given in the litteratue may slightly vary, the general rules are similar in nature.

1. **Saccade:** Saccade is very specific in nature; it is caracterized by a a speed scheme composed of an important acceleration that may reach 8000 $^{\circ}/s^2$ (Griffin and Bock, 2000) leading to a high eye velocity of more than 31.8 $^{\circ}/s$ (Gowen and Miall, 2006) and finnishes by an important deceleration phase. At its beginning and its end, saccade speed may be as low as 3 $^{\circ}/s$ (McSorley and Findlay, 2003), which could correspond to any movement, even a fixation. The amplitude of the saccade is proportional to its maximal speed (Engbert and Kliegl, 2003; Rodieck, 2003).
2. **Fixation:** Fixation is caracterized by a slow speed (less than 5 $^{\circ}/s$) and the fact the eye position remains within a disc corresponding to the foveal vision zone.
3. **Microsaccade:** As the saccade, the microsaccade is a repositionning movement. As such, it has the same acceleration/decceleration scheme. The only difference is that the distance between the original

and the final positions is not important enough to allow the eye to reach the speed at which capturing information is not possible. Considering the speed only, one could not know the true nature of such a movement but we consider that the eye speed should reach a maximum value between 10 and 31.8 $^{\circ}$/s. If the maximum velocity of the movement lies below 10 $^{\circ}$/s, the movement is either a fixation or a slow movement, using the parameters of Gowen and Miall (2006) on the opposite, we consider the movement to be a saccade if its velocity reaches more than 31.8 $^{\circ}$/s. Microsaccades have the same ballistic properties as saccades so that their amplitude is proportional to their maximum velocity.

4. **Slow movement:** Slow movements are not repositioning movements and they do not share the same balistic properties as saccades and microsaccades (acceleration scheme, amplitude proportional to maximum velocity) but the eye position does not remain in a disc whose size corresponds to the foveal vision as it is the case of fixations.

Classification algorithms

Identifying several parameters inside a unique algorithm is indispensable in order to better circumscribe the cinematics and avoiding artefact. As a consquence, the distribution and the balance of fixations and saccades will change according to the other parameter. Several studies have been conducted in order to tackel this question. In order to better describe the eye-hand coordination during a graphic task (drawing and tracing figures), Gowen and Miall (2006) classified fixations, saccades and smooth pursuits by applying the classical and constant thresholds. More recently, Nylström and Holmqvist (2010) proposed a new algorithm which aims at identifying saccades, fixations and pursuits by using adaptative thresholds in order to take into account the variability of parameters. In the present paper, instead of using velocity and acceleration by the mean of adaptive thresholds, eye movements are considered in their globality and caracterized according to their velocity, global acceleration scheme and the relation between maximum velocity and amplitude (Engbert and Kliegl, 2003; Rodieck, 2003), which could be considered as a signature for all saccadic movements. Thus, instead of using thresholds to distinguish fixations from pursuits or saccades, we propose an approach which first identifies saccadic movements. If a saccadic movement has a limited maximum velocity, it is classified as a microsaccade and if a non saccadic movement has a rather important velocity (between 10 and 31.8 $^{\circ}$/s), it is classified as slow movement (which could be a glissade or a pursuit depending on the context) instead of fixation. This classification may be achieved by two strategies: a first one starts by assigning movements to categories according to their speed and refines the classification with acceleration scheme, by expending saccades to integrate their beginning and end where velocity is smaller than the threshold. This is a *Speed First* strategy upon which is based the algorithm of Nylström and Holmqvist (2010). Another way is to start by classifying movements according to their acceleration scheme before refining the classification according to speed. This is the *Pattern First* approach leads to a much simpler yet more reliable algorithm that does not need adaptative thresholds as it will be presented here.

Considerations for implementation

The *Eye and Pen*© software collects positions of the eye through the eye tracker and the pen through the pen tablet. At more or less regular intervals, these two devices provide the software the coordinates of the position of the eye and pen. The data is then synchronized and stored in a file. As the clocks associated with each of the devices are synchronized, the data file produced by *Eye and Pen* accurately reflects the information it receives, which means it is possible that the frequency with which information is recorded is not constant. Furthermore, it is rare that the information from each of the devices are simultaneous. In order to facilitate any subsequent analysis, two preliminary steps are necessary: (i) filtering the signal and (ii) cadence at a fix frequency the two signals. Since we are not only interested by studying discrete events such as writing pauses or eye fixations, but also by continuous events like pen trajectories, eye movements or relations between these two signals, working with clean data is needed to avoid artefacts, especially when studying small events occurring in a short time range and small spaces.

This operation supposes to analyze the nature and scale range of degradations included into the signals recorded with *Eye and Pen*© in order to to select (or adapt) the optimal signal pre-processing (Teulings and Maarse, 1984; Marquardt and Mai, 1994). Various filters can be tested (Kernel estimates, FIR filter, Butterworth filter, Kalman filter- Abd-Almageed, Fadali and Bebis, 2002; Pulse Couple Neural Network filter- Chartier and Renaud, 2002).

Cadensing

Eye and Pen© records the two signals as they are delivered by the eye-tracker and the driver of the tablet, with different sampling frequencies (for instance: 400 Hz for eyetracker; 100 Hz for the tablet). As the information is not synchronous, we must extrapolate the information received and build a clocked file of records in which in an observation (eye and pen positions and pressure of the pen) is reassigned at regular intervals and synchronously. In this case, we chose to sample the data at a frequency of 200 Hz, an observation every 5 milliseconds, which seems a good compromise between the precision of the devices and the needs of the study.

Smoothing

The tangent speed is an important caracteristics for the classification of eye movements. To achieve good results, one may compute it in an acurate way. As the raw data is noisy, for technical reasons and due to the nystagmus, a first step toward good results is to smooth data. The following kernel function was used:

$$X'_t = \Big[X_{t-5}/6 + X_{t-4}/5 + \ldots + X_{t-1}/2 + X_t + X_{t+1}/2 + X_{t+2}/3 + \ldots + X_{t+5}/6\Big]/w,$$
$$\text{where } w = 2/6 + 2/5 + \ldots + 2/2 + 1.$$

Kernel smoothing as any smoothing function has a better effect when applied to cadenced data, otherwhise the time difference between observation being hazardous, some unexpected effect may be observed.

Description of the algorithm

1 – Initialization: After smoothing data, estimate velocity and acceleration for each data point. As the fixation is the only movement for which the speed may fall below 3 °/s, such data points are qualified as FIXATION while the others are classified as MSACCAD.

2 – Find elementary movements: Group MSACCAD data points in elementary movements (a sequence acceleration/deceleration), as shown on Figure 2.

3 – Caracterize each movement: Each elementary movement of the which is rated MSACCAD at this step is then caracterized according to its saccadic properties. An event is considered saccadic its maximum speed exceeds 31.8 °/s. An event whose maximum speed does not exceed 5 °/s is considered non saccadic (rated SLOWMVT at this step). An event whose maximum speed is between 5 °/s and 31.8 °/s is considered saccadic if it respects the amplitude/maximum speed property and has a maximum acceleration (or deceleration) higher than 400 °/s^2. On the example from Figure 2, A would be classified as saccadic while B,C,D,E and F would not. After this first discrimination, a saccadic movement may either be classified as SACCAD or MSACCAD (saccade or microsaccade) according to its maximum speed. After this caracterization, any movement caracterized SLOWMVT is again examined and reclassed as FIXATION if its maximum velocity does not exceed 5 °/s. Here, B,C,D,E and F would be classified as SLOWMVTs as their maximum speed exceeds 5 °/s.

4 – Group non saccadic movements: Non saccadic movements do not follow the same rules as saccadic ones and they are not caracterized by a single acceleration/deceleration cycle. To respect this property, all consecutive non saccadic movements of the same nature are merged. On the current exemple, B,C,D,E and F would thus be considered as a single SLOWMVT.

5 – Post-treatment: At this step, a first classification is obtained but some adjustments must be done in order to reduce the effect of the noise and we may need to reclassify slow movements that may lie at the edge of a definition i.e., reclassify SLOWMVTs whose velocity does not exceed 5 °/s for more than 75 ms as FIXATION. This requalification cannot be performed during the step 3 because some elementary movements may perfectly correspond to slow movements when merged with other slow movements but

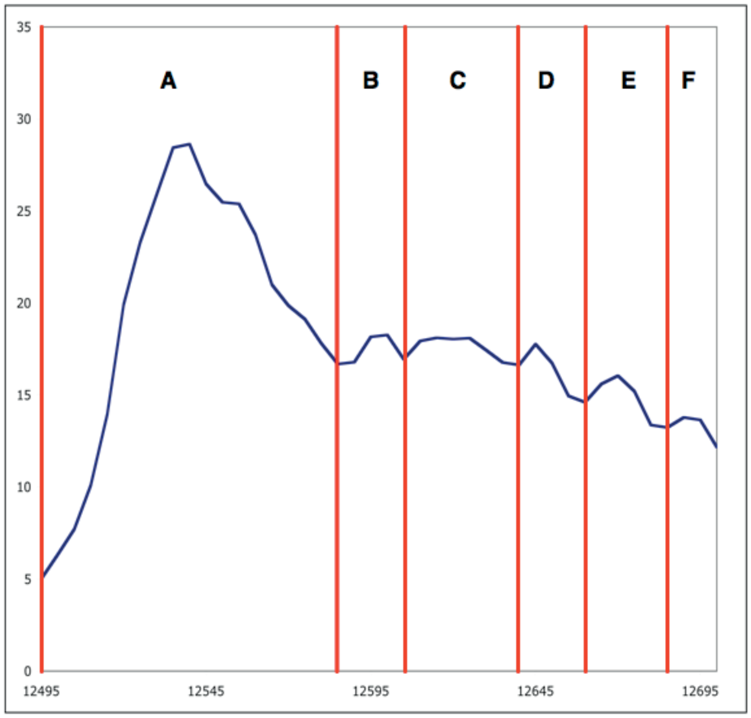


Figure 2: Decomposition of a sequence of data points into elementary movements

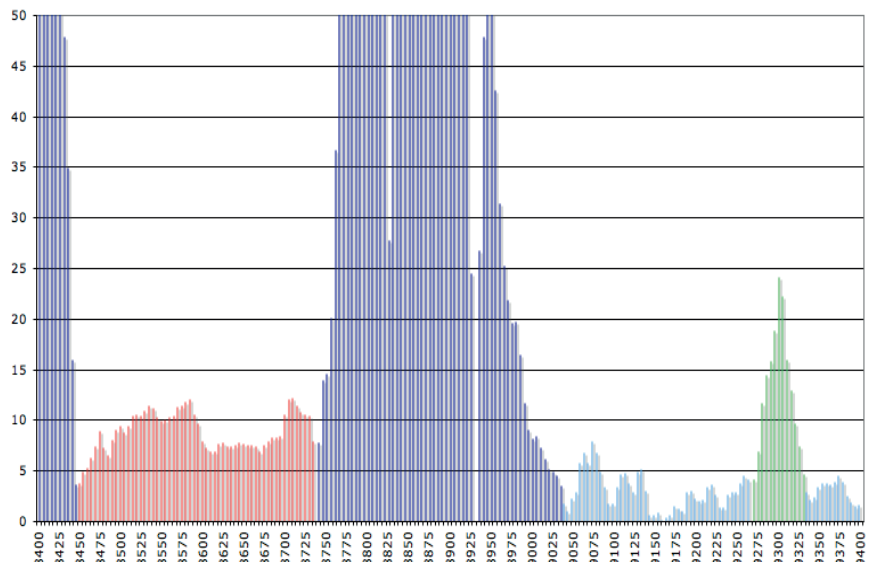


Figure 3: Excerpt representing the value of the eye speed during one second

have a short duration by themselves. Still to reduce the effect of noise, short movements (10 ms or less) are designed intependantly as SHORT; they have little impact on statistics when isolated but could artificially increase the total number of events otherwise. Finally, as the nature of some movements is altered by the post treatments adjustments, steps 3 and 4 must be performed again before the algorithm terminates.

Figure 3 shows an application example: the excerpt of one second of subject 128 writing the verb “Rougissait” (from time 8400 to time 9400). In details, we have the end of a 75 ms saccade followed by a 290 ms slow movement, then 3 saccades, one of 90 ms, one of 70 ms and one of 105 ms. Then comes a fixation for 230 ms, a microsaccade of 65 ms and the beginning of a 295 ms fixation.

Conclusion

This work helps us to deeper our understanding of the contribution of eye and graphomotor clues during written production, and in particular eye-hand coordination (Inhoff and Gordon, 1997). From a technological point of view, enhancements brought to the signal processing will be integrated in an *Eye and Pen*© software update.

This study relies essentially on the study of eye-hand coordination, it is necessary to determine if the classical kinematics parameters of handwriting can also be relevant variables, sensitive to the cost of orthographic processing.

References

[1] W. Abd-Almageed, M.S. Fadali and G. Bebis. *A non-intrusive Kalman filter-based tracker for pursuit eye movement. Proceeding of the 2002 American Control Conference* (2002) 1443–1447.

[2] D. Alamargot, D. Chesnet and G. Caporossi. *Technical and Experimental Advances in Studying On-Line Cognitive Processes in Translation from Source Material.* In: *Translation of Thought to Written Text While Composing: Advancing Theory, Knowledge, Research Methods and Tools, and Applications*, M. Fayol D. Alamargot and V. Berninger (Eds.) *in press.*

[3] D. Alamargot, D. Chesnet, C. Danzac and C. Ros. *Eye and Pen: a new device to study reading during writing. Behaviour Research Methods* **38**:2 (2006) 287–299.

[4] G. Caporossi, D. Alamargot and D. Chesnet. *Using the computer to study the dynamics of handwriting processes. Lecture Notes in Computer Science* **3245** (2004) 242–253.

[5] E. Chartrel and A. Vinter. *The role of visual information in the production of cursive letters in children and adults. L'année Psychologique* **106**:1 (2006) 43–63.

[6] D. Chesnet and D. Alamargot. Real-time analysis of the writer's graphomotoric and ocular activities: Interests of the "eye and pen" device. *L'année Psychologique* **105**:3 (2005) 477–520.

[7] R. Engbert and R. Kliegl. *Microsaccades uncover the orientation of covert attention. Vision Research* **43**:9 (2003) 1035–1045.

[8] E. Gowen and R.C. Miall. *Eye-hand interactions in tracing and drawing tasks. Human Movement Science* **25** (2006) 568–585.

[9] Z.M. Griffin and K. Bock. *What the eyes say about speaking. Psychological Science* **11**:4 (2000) 274–279.

[10] A.W. Inhoff and A.M. Gordon. *Eye Movements and Eye-hand Coordination During Writing. Current Directions in Psychological Science* **6**:6 (1997) 153–157.

[11] C. Marquardt and N. Mai. *A Computational-Procedure for Movement Analysis in Handwriting. Journal of Neuroscience Methods* **52**:1 (1994) 39–45.

[12] E. McSorley and J.M. Findlay. *Saccade target selection in visual search: Accuracy improves when more distractors are present. Journal of Vision* **3**:11 (2003) 877–892.

[13] R.C. Miall, H. Imamizu and S. Miyauchi. *Activation of the cerebellum in co-ordinated eye and hand tracking movements: an fMRI study. Experimental Brain Research* **135**:1 (2000) 22–33.

[14] K. Rayner. Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin* **124**:3 (1998) 372–422.

[15] R.W. Rodieck. *The density recovery profile: A method for analysis of points in the plane applicable to retinal studies (vol 6, pg 95, 1991). Visual Neuroscience* **20**:3 (2003) 349–349.

[16] D.D. Salvucci and J.H. Goldberg. *Identifying fixations and saccades in eye-tracking protocols. Proceedings of the Eye Tracking Research and Applications* (2000) 71–78.

[17] H.L. Teulings and F.J. Maarse. *Digital Recording and Processing of Handwriting Movements. Human Movement Science* **3** (1984) 193–217.