Gaze Shifts and Pen Velocity Minima During Line Copying with Consideration to Signature Simulation

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1 Introduction

There has been only one study that has previously investigated the eye and hand behaviours during signature copying (see Pepe et al. 2012). Although eye–hand behaviours have been previously reported on during other copying tasks (see Tchalenko and Miall 2009; Tchalenko 2007, 2009), none have investigated the timing between gaze shifts (saccades) and pen velocity minima (reductions in pen velocity) during copying of simple concatenated lines.

Previous drawing studies have reported that gaze shifts are frequently made at moments that the pen slows to a velocity minimum during a stroke (see Reina and Schwartz 2003; Gowen and Miall 2006). Similar behaviours have also been reported on in aiming tasks (see Helsen et al. 1998; Helsen et al. 2000), shape drawing (see Ketcham et al. 2006) and other tasks (Neggers and Bekkering 2000). Gowen and Miall (2006) recorded the eye movements and pen kinematics of subjects during shape drawing and tracing. For these tasks, respectively, they found that 43 and 47 % of saccades were made within ± 100 msec of a velocity minima. They propose this eye–hand behaviour could indicate attention returning to eye movement planning before the hand movement has been fully programmed, whilst others suggest this behaviour could be related to the eyes receiving feedforward information about the upcoming movement (Ketcham et al. 2006; Reina and Schwartz 2003).

Pepe et al. (2012) explored the eye movements and pen kinematics of simulators (forgers) during signature simulations of two types of signatures with different complexity ratings (see Found and Rogers 1998). Although the authors found that copying these signatures evoked different eye and pen kinematic behaviours, the study did not report on temporal behaviours during copying, the nature of these behaviours and their relevance to signature simulation. Therefore, the current study was, in part, conducted to address this issue by exploring the eye–hand behaviour in a task similar to, but not synonymous with, signature copying. More specifically,

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it aimed to determine the nature of the temporal relationship between the movement of the eye and hand during a copying task and to determine the implications of this relationship with respect to signature simulation.

2 Methods

2.1 Participants

Twenty healthy subjects with normal or corrected to normal visual acuity levels participated in the study. All subjects confirmed the absence of any neurological conditions, disorders or injuries known to affect eye or hand movements, or to taking any medications known to affect eye or hand movements. Of the 20 subjects, five subjects whose data could facilitate an accurate analysis of eye–hand interactions were selected. Of the five subjects, four were female and one was male. The age range was 23–44 years with a mean of 30 years.

2.2 Materials and Apparatus

Subjects sat on a kneeling chair at a desk with a horizontal surface and an attached PTZ-1230 12×12 Wacom Intuos 3 digitising tablet. An inking pen was used for recording subjects' raw and digital kinematic data (FFT low-pass 12 Hz filter). A Tobii X-120 eye tracker attached under the table facing upwards at an angle of 68° captured the eye movements of subjects. Subject's viewing distance from the eye tracker ranged between 54 and 62 cm, depending on their height. A fixation was classified using the Tobii fixation filter, which was customised to a velocity threshold of 30 pixels/window and a distance threshold of 15 pixels. This filter best matched the raw sampling data. The sampling rate of the eye tracker was 60 Hz and had an accuracy of 0.5° and the digitising tablet recorded at 200 Hz with an accuracy of 0.25 mm in the x and y direction. An external Basler scA640-120gc digital camera was used to record the trials and the video footage was superimposed with eye-gaze position using Tobii Studio version 2.0.2 software. The camera was positioned directly above the centre of the display screen and had a resolution capture of 658×492 pixels. The camera was set to 91 frames per second and the video feed was encoded using the default Microsoft video 1 codec within Tobii studio. A headrest was used to keep subject's head position constant throughout testing to improve the spatial accuracy of eye tracking.

2.3 Data Gathering

Subjects were first calibrated to the eye tracker using a five-point calibration grid positioned on the digitising tablet surface. Once properly calibrated, subjects were

Fig. 1 Exemplar image copied by subjects

then required to have a practice attempt at copying the word 'practice' to insure desired eye-tracker accuracy and reliability, as well as subject comfort.

Subjects were required to copy a line image called the exemplar image, which was made up of eight connected lines, as shown in Fig. 1.

The image was presented and copied three times consecutively. Subjects were instructed to copy to the best of their ability. All copies were drawn at least 5° below the exemplar image to control for any potential effects arising from parafoveal vision.

3 Results

Gaze data was explored qualitatively in order to determine the extent of any temporal relationships between the eye and hand during copying. This required frame-by-frame analysis of the recordings taken using Tobii Studio version 3.0.3. Camera frames were recorded every 11 milliseconds. Of the three repeated trials, the trial that best allowed for an accurate temporal analysis between the eye and pen was analysed. This was determined by the number of pen velocity minima and their positions, as these factors affected the ability to determine the time elapsed between gaze shifts and velocity minima. Trials with higher writing velocities and therefore more automated movements tended to be selected. The coinciding of gaze shifts and velocity minima were identified by reviewing camera recordings of the drawn copy and an image of where the copies' velocity minima occurred.

It was found that the majority of gaze shifts coincided with velocity minima, regardless of whether gaze was directed at the exemplar image or the copy. Figure 2 is an image of a copy trial produced by one of the subjects.

Velocity minima that were overlapping spatially (see Fig. 2) were counted as one velocity minima. During the trial in Fig. 2, a gaze shift was made at the fifth (from the left) velocity minima. This can be viewed in Fig. 3, which shows the occurrence of a gaze shift as the pen reached that position.

Figures 2 and 3 illustrate that as the pen reached a velocity minima, the subject's gaze shifted from left to right. This gaze shift was represented by two fixation circles, the former (left) and the latter (right). Figure 3 also shows that as the pen reached the equivalent position of the eye gaze, the gaze shifted—a behaviour

Fig. 2 Example image of a subject's copy attempt showing the locations of pen velocity minima (*circles*)

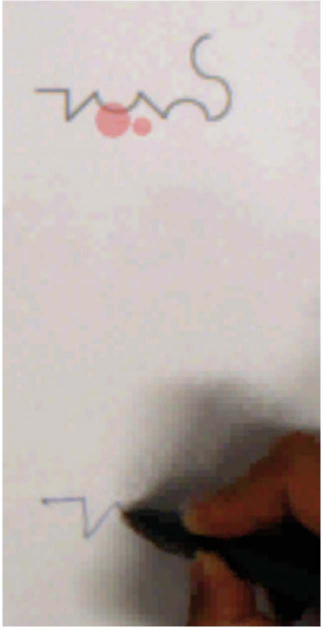

Fig. 3 An observed gaze shift (from *left* to *right*) at the moment of a pen velocity minima during copying

reported previously in drawing (see Tchalenko 2007; Gowen and Miall 2006), pointing (see Neggers and Bekkering 2000) and in face copying (see Tchalenko 2009).

Table 1 is a summary of the number of velocity minima and gaze shifts and the percentage of gaze shifts that coincided within a 33-millisecond interval.

As there tended to be more velocity minima than number of gaze shifts, not all velocity minima coincided with a gaze shift. On average, almost two thirds of gaze shifts coincided with a velocity minima, with a large proportion of these instances occurring at moments when the pen was still.

Table 1 Summary of gaze shifts, velocity minima and percentage of gaze shifts coinciding

Subject	Total gaze shifts	Total velocity minima	Total Coinciding (within 33 msec)	Percentage of gaze shifts coinciding
1	11	15	7	63.64
2	15	16	11	73.33
3	23	20	18	78.26
4	6	11	3	50.00
5	14	16	9	64.29
Mean	13.8	15.6	9.6	65.90

4 Discussion and Conclusions

The aim of the current study was to determine the nature of the temporal relationship between the movements of the eye and hand during the task of line copying. The results show that there was a close relationship between the eye and hand, with an average of two-thirds of gaze shifts occurring at moments the pen was spatially at or temporally within 33 milliseconds of a velocity minima—the former being more common than the latter. A possible explanation for this finding is that subjects were prioritizing the order of cognitive processes relevant to the task and also attempting to reduce the impact of delays in cognitive processing associated with making gaze shifts (see Rayner 1998). The advantage of making gaze shifts when the pen is still or moving slowly is that it would allow for extra time, with relation to pen distance covered, for visual processing of the next stroke from the exemplar image, or checking of spatial output of the drawn image—a process important for maintaining the spatial quality of the copy (see Smyth and Silvers 1987). This idea is consistent with the view that at these moments, there is more relative time to gather and integrate visual information (Ketcham et al. 2006). The presumed problem with making gaze shifts during moments the pen is moving quickly is that relevant cognitive processes may become suspended during this time (see Irwin et al. 1996). In addition, if further time is then required to process the visual information of the newly fixated area, large distances could be covered by the pen in the absence of relevant, or necessary cognitive processing. Given the pen can move relatively large distances over short periods of time, these delays to processing could be enough to affect the quality of output. Therefore, it is proposed that gaze shifts can come at a cost during this task. This cost can be somewhat mediated by the simulator by using certain eye–hand behaviours, and it is these behaviours that suggest tactical decision making about the execution of processes relating to copying.

Although simulators may be able to mediate costs associated with making gaze shifts during line copying, this may not be true for signature simulation. The problem associated with copying signatures is that the same strategy may not be as viable. The reason for this is that pausing during a signature simulation task can compromise line quality—a characteristic important for determining authenticity of specimen signatures. Because authentic signatures tend to be executed fluently (tend not to show abrupt pen pauses, unnecessary pen lifts or moments of dysfluency caused by slow pen movements and hesitations), the line quality is important in determining the authenticity of a signature simulation. Given line quality must also be appropriately maintained by the simulator, the strategy of simulators taking advantage of momentary pauses during line copying is unlikely to be as viable for signature simulation. This may be the reason why spatial accuracy and line fluency are thought to trade off (see Hilton 1982) during signature simulations.

The present study has provided evidence of a close temporal relationship existing between the eye and hand in the task of line copying. It is thought that this relationship may serve to help mediate the costs associated with making gaze shifts that can impact upon the ability to accurately copy an image. Future studies should determine if a similar relationship is present in the task of signature copying. In addition, future studies should aim to investigate the effects of line length and fluency on the eye–hand behaviour and quality of output during copying.

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