Effects of writing speed upon modes of signature simulation: A kinematic analysis

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Abstract: *To better distinguish between traced and freehand signature simulations, 12 participants practiced upon a WACOM SD420 graphics tablet tracing a historical signature at Slow or Very Slow speeds, with a subsequent comparison of freehand and traced signature simulations. Kinematic analyses focused upon stroke efficiency and pressure, while computer algorithms determined variability of simulations around an original. Traced simulations had reduced spatial variability after practice. Very Slow simulations were more dysfluent, had greater spatial error and employed more pressure. Pen pressures varied more with speed during freehand reproductions. Writing speed was an important contributor to line quality and spatial correspondence during signature simulation.*

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1. Introduction

Document examiners focus upon line quality and the extent to which a questioned signature is spatially consistent with the variation in originals (Ellen, 1989), in their efforts to detect forgery. This reflects an underlying assumption that signatures are based upon unique and personalized motor programs (Found & Rogers, 1996). These personalized motor programs make it difficult for forgers to unlearn their own writing habits and mimic those of another, and to produce writing that corresponds in form and shape to that of the original (spatial correspondence), without relying more upon vision and moving in a slower and more hesitant manner (poorer line quality) (Van Gemmert & Van Galen, 1996).

While naive forgeries employ tracing, more skilled forgeries employ a freehand style and are more difficult to detect (Halder -Sinn, l 994). In this regard, more sophisticated techniques might assist in addressing these issues. For example, in a study of spatial correspondence, Leung, Cheng, Fung, and Poon (1993) used a light box and electronic calipers to determine the percentage of superimposability during free-hand simulations. They reported that people focused upon salient features to the neglect of other less distinctive (but nevertheless diagnostic) features, such as inconspicuous detail and writing direction, when attempting to reproduce signatures. In a subsequent study, Leung, Fung, Cheng and Poon (1993) addressed the superirnposability of traced simulations. Traced signatures had a greater superimposability. This study also used a pressure meter to examine pen pressures associated with signature simulation, reporting that traced signatures were more hesitant, and had smaller variations in pen pressures. Such issues have also been addressed using kinematic analysis, with Van Gemmert and Van Galen (1996) reporting that freehand simulated signatures were slower and more dysfluent than the original signatures.

While for some, document examination assumes the existence of an underlying motor program, there

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Figure 1. Signature of the historical figure simulated in the present study (Rob Morris a signatory to the American Declaration of Independence).

have been an increasing number of challenges to the concept of a motor program (Abernethy & Spar row, 1992). Indeed Latash (1993) argued against the existence of a motor program suggesting that a motor program exists only for those effectors used during the acquisition of handwriting, and that otherwise samples of writing from a variety of individuals and effectors were indistinguishable. This leads to the suggestion that the signature reproductions of different individuals merely vary along a dimension of drawing skill (Latash, 1993). In addition, others have suggested that the kinematic features of movement may simply be a function of movement dynamics (e.g. Kelso & DeGuzman, 1991). For these reasons, we addressed the impact of practice upon the ability to trace signatures while controlling the speed of movements. A kinematic analysis of line quality and spatial correspondence may provide further insights into ways to distinguish, in the first instance, features of practiced and unpracticed simulations, and in the second instance, features of traced and freehand signature simulations.

2. Method

2.1 Participants

Twelve participants, (six males and six females) aged between 19 and 29, volunteered their time for this study. Participants were right handed, as determined by a handedness questionnaire (Bradshaw, Bradshaw, & Nettleton, 1990). All had normal handwriting skills that were used on a daily basis. Participants with poor handwriting quality and/or poor fluency were excluded from the study.

2.2 Apparatus and Task

A Mitac 486 laptop computer was used to collect data from a Wacom SD420 graphics tablet, which recorded X and Y coordinates of a digitizing pen at a frequency of 200Hz. The non-inking pen was sensitive to 63 levels of pressure (which were calibrated in grams). Using the digitizing pen upon the graphics tablet, participants traced a previously digitized and filtered signature of a deceased historical figure. Since forgers may only have limited access to genuine signatures and typically need to disregard their own writing style, we used the signature of a historical figure. And while we originally intended to use John Hancock's signature from the American Declaration of Independence, we finally chose another signature (Rob Morris, also from the Declaration of Independence) that did not involve the pen lifts which would ultimately complicate signal processing and data analysis (see Figure 1).

3. Procedure

Participants were given some initial practice tracing the signature to familiarize themselves with the task and equipment. Data was then collected in blocks of ten trials. The effects of practice were addressed over four blocks , with a rest break after each block of trials. Participants were instructed to trace the signature as accurately as possible in a specified time. Feedback as to movement duration was given after each trial. Since tracing is slower than normal handwriting, we describe the variations in movement speed in this study as involving Slow and Very Slow conditions. Slow trials were to be completed in under 10 seconds, whereas Very Slow trials were to be completed in under 20 seconds. The speeds required for each trial were alternated within a block of trials; that is, participants were told either to "trace fast" (Slow condition) or to "trace slow" (Very Slow condition) for alternate trials, with the starting order being counterbalanced for participants. After these four blocks of tracing practice, participants

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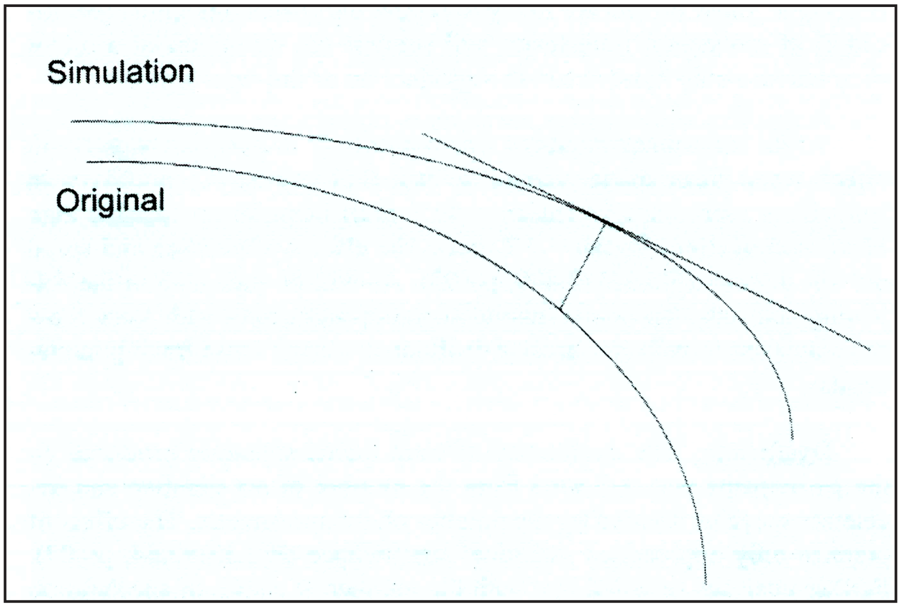

Figure 2. Calculation of spatial correspondence involving the calculation of the distance from the simulation to the original, along a perpendicular drawn from the tangent at that point.

did a further four blocks of ten trials in which the signature was reproduced freehand or traced while controlling movement duration. When performing freehand reproductions, participants were able to view the model signature, which was placed at the top of the graphics tablet.

4. Data Analysis

Coordinates were filtered at 10 Hz and double differentiated to produce tangential velocity and tangential acceleration functions. For each individual trial, Spatial Variability, Dysfluency and Pen Pressure were determined. Spatial variability at a point was defined as the distance of a perpendicular drawn from the tangent at that point to the original signature, and was calculated as the root mean square spatial error away from the authentic signature (see Figure 2). In the case where a perpendicular line from a tangent did not intersect the original signature, then the spatial error was defined as the distance to the nearest part of the original signature. Spatial variability could only be addressed for traced signatures. Dysfluency of the writing produced by the participant was determined from a count of the number of accelerative and decelerative impulses divided by the number of submovements. Submovements were determined from the number of peaks in the tangential velocity function. The mean and standard deviation of pen pressure for each trial were determined over the period where the pen was depressed. Each of the dependent variables was submitted to separate two way repeated measures analysis of variance, employing a practice by speed (4x2) design and a mode of production by speed (2x2) design when examining practice or mode of production.

5. Results

5.1 Practice

5.1.1 Movement Speed. Movement duration was controlled in order to dissociate the effects of practice from those of speed. Movement duration was successfully varied, since there was a significant difference in the mean tangential velocities between the Slow (mean = 51.2 mm/s) and the Very Slow conditions (mean = 35.3 mm/s) ($F(1,11)=160.07, p<.01$). Studies using similar technology report handwriting velocities in the range of 100 to 200 mm/s, which suggests that participants' tracing movements were about one third (Slow) and one fifth (Very Slow) of normal writing speeds.

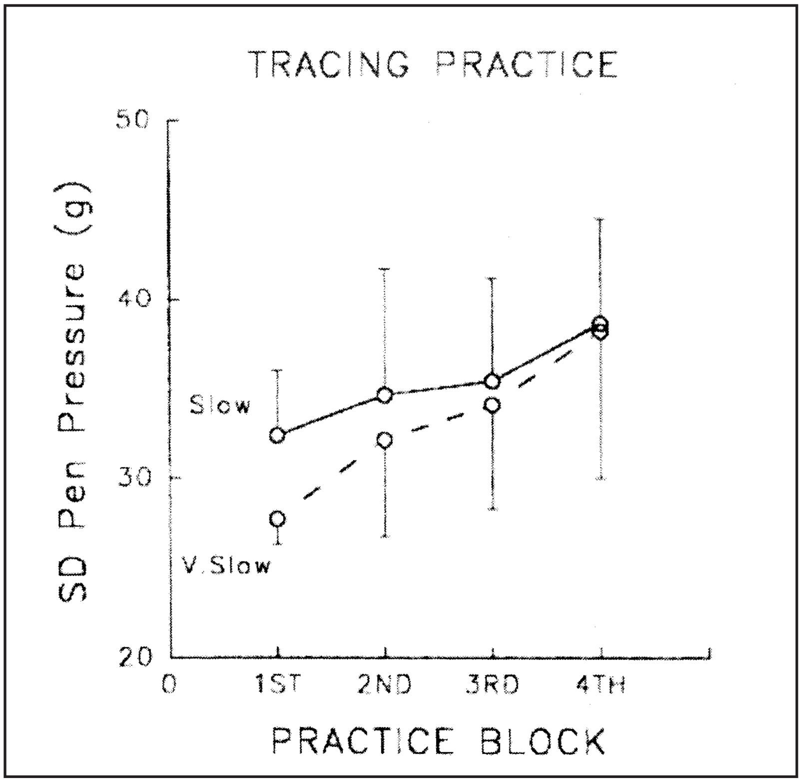

Figure 3. Impact of speed and practice upon variations in pen pressure during tracing.

5.1.2 Spatial Variability. Since any differences in spatial correspondence may simply reflect variations in speed of movement, we controlled movement duration. There was a significant effect of practice on the variability of the traced reproductions around the original (F(3,33)=0 10.85, p<.05), dropping from 10.29 to 8.7 to 8.1 to 6.9 over blocks of practice. Traced reproductions showed a greater correspondence with the original after practice. Since movement duration was controlled, these effects are likely to reflect improvements in the specification of movement trajectories and suggest the formation of a motor program allowing more accurate reproduction of the signature .

While movement duration was controlled, it did have significant effects upon mean spatial variability data (F(1.1)=61.68, p<.05), with Very Slow reproductions (mean 13.7 mm) being more variable than Slow reproductions (mean = 3.3 mm) . The effects of practice and speed did not interact (F(3,33) 0 2.409, p>.05). As will be indicated in the following analyses, the poorer spatial accuracy associated with Very Slow trials appears to reflect a greater dysfluency during these tracing movements.

5.1.3 Dysfluency. The dysfluency of each traced signature produced by the participants was indicated from the number of accelerative and decelerative cycles divided by the number of submovements. The effect of practice only approached statistical significance (F(3,33)=2.64, p<.07). Further analyses revealed that both the number of cycles of acceleration and deceleration and the number of submovements varied with practice. At the beginning of practice, participants required 72.98 cycles of acceleration and deceleration and 30.20 submovements, while they required 75.71 and 30.92 for the fourth block of practice. This suggests that as participants were tracing the signature they were mapping more complexity onto their movement, allowing their simulation to more closely approximate the original signature.

Movement duration had stronger effects on dysfluency (F(l,11)=5.37, p<.05), with Very Slow reproductions (mean = 2.46) being more dysfluent than Slow reproductions (mean = 2.39). Tracings produced within a shorter period of time exhibited better fluency when compared to those produced over a longer period of time. Nevertheless, these effects were

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not great. We suspect the poorer spatial correspondence observed for Very Slow movements reflects the greater amounts of hesitancy and directional uncertainty in these movement trajectories.

5.1.4 Pen Pressures. Average pen pressure during signature reproduction varied significantly during practice (F(3,33)=6.908, p<.05), but not in a linear fashion, varying from 172 to 197 to 186 to 183 gms over the four blocks trials. This implies that pen pressure is influenced by a number of factors during practice. There was also a trend for pen pressure variability to increase with practice (F(3,33)=2.262, p<. 1).

Movement duration also had a significant impact upon pen pressures (F(l , 1 1)=7.54, p<.05), with Very Slow movements (mean = 188 gms) having a greater pen pressure than Slow movements (mean = 18 l gms). However, Slow movements were significantly more variable in their pen pressures (mean= 35 gms) than Very Slow movements (mean= 33 gms) (F(l,11)=14 .01, p<.01) (see Figure 3). While these effects are not dramatic, it indicates that faster tracing may have more " spontaneity and vigor" than slower tracing (Leung, Fung, Cheng, & Poon, 1993). The greater constraints placed upon the movement system during slower tracing apparently increased tension in the limb and increased average pen pressure, while placing limits upon its variability (Van Gemmert & Van Galen, 1996).

6. Mode of Production

While tracing is the simplest form of forgery, freehand simulations are more difficult to detect and require a closer examination of line quality (Halder-Sinn, 1993). since there is a reduced emphasis upon visual guidance. We, therefore, also considered characteristics of both traced and freehand simulations of signatures.

6.1 Dvsfluency. Following the practice trials, simulations produced by tracing were compared to those produced freehand. An analysis of variance indicated that dysfluency did not significantly vary between traced (mean = 2.40) and freehand (mean = 2.46) modes of production (F(i 11)=2.091, p>.05). Either practice has reduced the differences between these modes of control, or previously reported differences in part reflect differences in speed of movement This may be of concern to document examiners. But although such observations appear to indicate that line quality will not vary between traced and freehand reproductions, this only means that line quality may not be adequate to determine mode of production after practice and within the range of speeds considered in the present study.

In this study, all signatures were reproduced at speeds much slower than those typically employed when signing documents. Even so, movement duration was again an important factor, having significant effects upon dysfluency (F(l,11)=8.77, p<.05). Very Slow trials (mean = 2.46) were more dysfluent than Slow trials (mean = 2.40). These effects were not modified by mode of production (F(l,11)=0.05, p>.05). This implies that it may be difficult to determine whether or not fraudulent signature reproductions are traced (Halder-Sinn, 1994) by kinematic means when signatures are reproduced at slower speeds.

6.2 Pen Pressures. While it might be expected that signatures produced by the tracing method would exhibit higher average pen pressures, an analysis of variance did not reveal a significant effect (F(I,11) = 1.33 l, p>.05). Tracing as a mode of control has been characterised by increased constraints placed upon the spatial appearance of the signature. These constraints have been suggested to increase biomechanical stresses, which result in increased pen pressure. This does not apply to freehand simulations, since this mode of production is not based as much upon feedback. Nevertheless, the absence of significant differences in average pen pressures between the modes of production suggests that any differences are reduced after practice as a motor program develops. That is, participants after practice were able to produce movements that more closely approximated those for freehand reproductions. Therefore, in terms of average pen pressure, a difference between the two modes of production was not revealed because the tracing method did not involve the constraints imposed early in practice. Such observations are of concern for the detection of forgeries. The absence of these effects after practice implies that movement speed could be more important than the mode of production during signature verification. This argument is thus in keeping

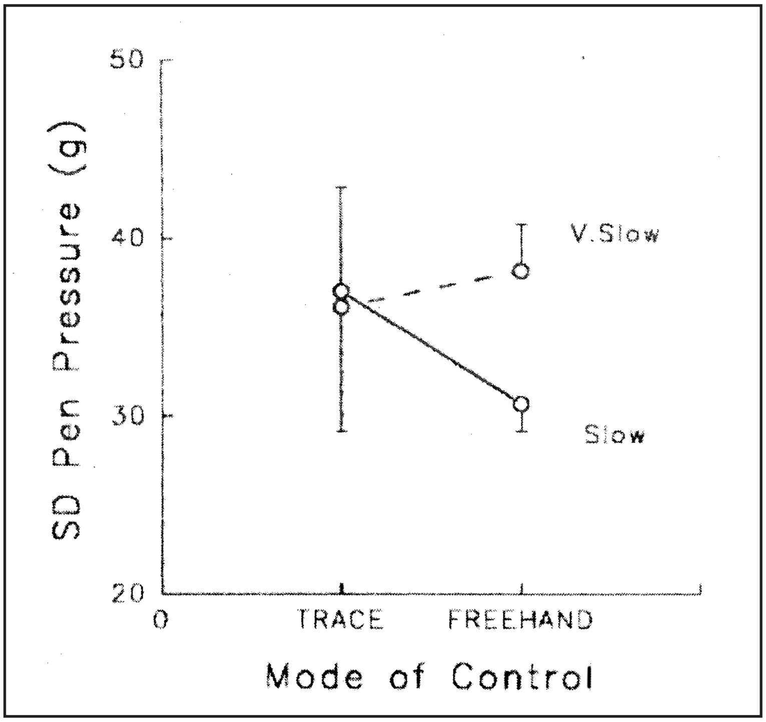

Figure 4. Impact of speed and mode of simulation upon variations in pen pressure.

with critics of motor programs that emphasise the importance of the dynamic features of movement.

Movement duration had significant effects on mean pen pressure (F(l,11)=9.86, p<.01). Very Slow movements were associated with greater pen pressures (mean= 194 gms) than those of Slow movements (mean= 186 gms). Nevertheless, while an examination of variability of pen pressures indicated that Very Slow reproductions (mean= 37 gms) were significantly more variable than Slow reproductions (mean = 34 gms), these effects must be interpreted in the light of a significant interaction with mode of production (F(l,l 1)=16.66, p<.01). As may be seen in Figure 4, the impact of movement duration was much smaller upon tracing (mean diff. = 0.9) than when producing signatures freehand (mean diff. = 7.5). While signatures produced at Very Slow movement speeds exhibited larger and more variable pen pressures, freehand productions exhibited a greater range of variabilities as a function of movement duration. The smaller changes in pressure variabilities with speed for traced reproductions reflects the greater constraints upon this mode of reproduction.

7. Discussion

To better distinguish the characteristics of traced and freehand forgeries, this experiment examined how the features of a traced signature change with practice. We controlled variations in movement speed because some theorists dispute the existence of a motor program and argue for the sufficiency of movement dynamics as an explanation of movement. Movement speed was a potent, but not a sufficient explanation of the present data. There were effects over and above those of speed. for example, there was a better spatial correspondence with practice when controlling movement duration (apparently because more complexity is mapped onto subsequent reproductions). Nevertheless, once movement duration was controlled, it was difficult to distinguish between the effects of practice and mode of production. In particular, it was difficult to· distinguish between traced and freehand reproductions after practice (and at the slower speeds used) on the basis of movement kinematics alone. Only the greater range of pressures available at different speeds during freehand reproductions tended to distinguish between the traced and freehand reproductions.

In the present study, movement duration had the more reliable effects upon line quality and spatial correspondence. Of note was the poorer spatial correspondence for the Very Slow trials. This was unexpected on the basis of the speed/accuracy trade off literature (Pachella, 1974), which suggests that it is the faster responses that are inaccurate. Nevertheless, faster movements can be associated with better performance under certain circumstances, particularly where fluent or consistent output is required (see Pew, 1974). In the present study, a consideration of movement kinematics indicates that movements at slower speeds were more hesitant and variable. We therefore suspect the poorer spatial correspondence at slower speeds reflects the nature of our measure of spatial correspondence, since it is sensitive to the extent to which the reproduction is close to and parallels the original. As our spatial variability measure was sensitive to both spatial correspondence and line quality, it could prove a useful adjunct in algorithms for document examination and writer identification (e.g. Greening, Sagar, & Leedham, 1996; Leclerc & Plamondon, 1994; Plamondon & Lorette, 1989).

Unfortunately, our algorithms could not address spatial corresponence for both traced and freehand reproductions. To do so requires more sophisticated stroke segmentation and normalisation algorithms. While the algorithm used in the present study could calculate the small spatial deviations associated with traced reproductions, the degree of error was very much greater for freehand reproductions. This was unfortunate, since the high spatial deviations in freehand simulations are the cues which allow document examiners to detect freehand simulations. And while the spatial deviations were too great for our algorithm to assess, our study does indicate a greater range of pen pressures as a function of speed for freehand reproductions.

In the present study a non-inking pen was used for convenience, and to allow the measurement of pen pressures. This meant that during tracing, immediate visual feedback was available as to pen tip position relative to the original, but a longer lasting form of visual feedback was not available to participants. And during freehand reproductions, participants could only provide the immediate visual feedback with the program they had learnt for the signature. The effects of using non-inking pens upon movement kinematics during handwriting has been considered (Slavin, Phillips, & Bradshaw, 1996). Non-inking pens tend to produce longer writing strokes of increased duration, but the effects are not appreciable on other kinematic indices such as dysfluency (Slavin, Phil lips, & Bradshaw, 1996).

To understand and distinguish between the characteristics of forgeries produced by tracing and freehand simulations, this experiment compared two modes of signature simulation in terms of both the dysfluency of writing and average pen pressure at different movement speeds. Within the slower range of writing speeds considered, it was found that both dysfluency and average pen pressure did not change as a function of the mode of production employed. This implies that after practice, movement speed is the only factor distinguishing the two modes of simulation, rather than a unique personalized program. Indeed, such observations imply that speed, rather than mode of production or complexity (Kao, Shek, & Lee, 1983) is a major determinant of writing pressures.

The lack of differences between traced and freehand reproductions after practice could present problems for document examiners when considering a questioned signature, since after practice no differences were observed between traced and freehand reproductions within the slower range of writing speeds considered. Nevertheless, this study only addressed different styles of forgery. It would thus be of interest to compare originals with forgeries. And while we employed a historical signature to simplify analysis in the present study, it would be of value to compare the kinematics of an original with reproductions (see Sita & Rogers, 1999; Van Gemmert & Van Galen, 1996), and assess the extent to which they spatially correspond over successive original signatures (e.g. Rogers & Found, 1996). Even so, while practice and mode of production have an impact upon signature simulation, the present study demonstrates that movement duration has potent effects upon line quality and spatial correspondence.

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