Motor constancy and the upsizing of handwriting

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Abstract
Although handwriting can vary in size, it remains remarkably similar in form, demonstrating motor constancy (equivalence). A consideration of changes in writing size may indicate: (1) how rescaling is accomplished, and (2) those invariant features that remain constrained under size variation. In the experiment reported here nine participants wrote the word “minimum” (without dotting “i”s”) in cursive text, under three size conditions on a SmartBoard. The standard deviation of stroke slope did not change its relationship to mean stroke slope, but stroke durations and lengths did vary. Kinematic analysis indicated that the number of submovements, their efficiency, and their kinematic structure varied across the three writing size conditions. The results suggested that motor constancy does not merely reflect a simple change in a single parameter of scale.

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1. Introduction

A handwritten signature is similar irrespective of whether it is written on paper, on a credit card, or on a blackboard. The tendency for such motor outputs to be equivalent irrespective of the effectors employed is called motor constancy (motor equivalence) (Raibert, 1977). Motor constancy is of practical interest, as computer interfaces (Baber, 1997) and handwriting recognition capability (e.g., Microsoft Vista, in online chatting programs such as MSN Messenger and on handheld devices such as mobile phones and Blackberry) are proliferating, such that algorithms are now being required to recognize handwriting in a variety of sizes and orientations (Araujo, Cavalcanti, & Filho, 2006, 0167-9457/$ - see front matter Crown Copyright © 2009 Published by Elsevier B.V. All rights reserved. doi:10.1016/j.humov.2009.07.004

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The use of such software online tends to assume that a signature will be constant, irrespective of size or effector, but this may not be the case (Araujo et al., 2006, 2007). The present paper tests this assumption for larger interface devices (i.e., blackboard size), considering kinematic changes in handwriting as a function of size.

A hypothetical construct called a motor program has been thought to underpin motor constancy (Schmidt, 1982). A generalized motor program is a representation in memory that serves as a basis for generating responses within a class of movements. The generalized motor program consists of a set of invariant features that are shared by movements within a class with specific movement parameters being assigned prior to initiation by a recall schema (see Summers & Anson, 2009). A generalized motor program supplies broad abstract details for the movement and then resolves issues of storage and novelty by mapping on specific parameters such as size or duration as required. A hypothetical motor program potentially resolves changes in the size of handwriting by adjusting a single parameter (Schmidt, 1982), but the nature of the parameter has been subject to debate.

Viviani and Terzuolo (1980) suggested that centralized timing would allow for variations in size, while controlling the temporal relationships between writing strokes. Execution times are approximately constant, because the velocities of movements are related to their required extents (Vinter & Mounoud, 1991; Viviani & Terzuolo, 1980). For curved movements this relationship potentially emerges as a one third power law relating tangential velocity and radius of curvature (Lacquaniti, Terzuolo, & Viviani, 1983; Vinter & Mounoud, 1991).

However, the invariance of timing has been questioned (Wann & Nimmo-Smith, 1990; Wright, 1993). Wright (1993) noted writing times were not invariant over changes in writing size. Wann and Nimmo-Smith (1990) found significant differences in relative timing when varying writing size and speed. In addition, the power law has been observed to vary as a function of size of movement (Schaal & Sternad, 2001) or effector (Phillips, 2008). Hence, other researchers feel that equivalence during handwriting is accomplished by varying a time parameter while controlling relationships between spatial features such as the lengths of writing strokes (e.g., Teulings & Schomaker, 1993).

An identification of the parameters that vary and that are more tightly constrained may indicate the elements of movement (Schmidt, 1984) and specifically handwriting that are controlled (Teulings & Schomaker, 1993). If timing is invariant, changes in size should be accomplished with minimal changes in the durations of movement (Wright, 1993). If spatial features are invariant, changes in size should be accomplished by varying timing, while maintaining tight control over variations in the extents of movements.

Most studies of changes in handwriting size have compared normal with approximately twice normal size (e.g., Maarse, van Galen, & Thomassen, 1989; Meulenbroek & van Galen, 1986; van Doorn & Keuss, 1993; Wann & Nimmo-Smith, 1990). However, this does not capture the variation of scale possible given the nature of current interface devices available in our schools (i.e., computerized Blackboards), and so the mechanisms involved in this resizing of handwriting remain unclear. Indeed, Meulenbroek, Rosenbaum, Thomassen, Loukopoulos, and Vaughan (1996) dismiss the issue of invariance, instead suggesting that when considering motor constancy, the issue is how to write the same letters with different effectors (or on surfaces with different orientations or with different sizes) such that the written product can be recognized later.

Handwriting is considered to be the product of two coupled oscillators (Dooijes, 1983; Hollerbach, 1981), with the shape of letters arising as a function of the phase relationships between oscillators. For normal handwriting, the \( y \) oscillator typically corresponds to the movements of fingers and has a greater role in letter formation, while the \( x \) oscillator typically corresponds to the movements of the wrist and has a greater role in the spacing of writing (Dooijes, 1983; Meulenbroek & Thomassen, 1991; Teulings, Thomassen, & Maarse, 1989). Nevertheless, writing is required in a variety of sizes, surfaces, and orientations. When downsizing handwriting (as per a signature on a credit card), a simple reduction in the extent of oscillations may be feasible (but see Araujo et al., 2006, 2007), however when upsizing handwriting (as per writing on a blackboard) it is likely that additional effectors are involved, with an increasing use of more proximal muscles (Guiard, 1988; Rogers & Found, 1996) to magnify the movements. As these different oscillators are likely to have different biomechanical properties, changes in the relationships between the oscillators would be expected to manifest as changes in the slopes of handwriting movements (see van Doorn & Keuss, 1993; Wann & Nimmo-Smith, 1990).
The present study sought to characterize increases in the size of handwriting associated with the use of classroom blackboards. A kinematic analysis of writing strokes could offer insights into mechanisms involved in any rescaling of handwriting. Conceivably a simple reparameterization of a generalized motor program would retain the general structure, such that the number of writing strokes remains constant, while increasing in their extent. Alternatively, an increase in writing size might be achieved by adding more submovements during writing. A consideration of features that are invariant during size changes may indicate the core elements constrained by the motor system (Schmidt, 1984). Changes in slopes of writing strokes are likely to reflect differences in the oscillators employed to produce writing movements.

2. Method

2.1. Participants

Nine right-handed volunteers (5 males and 4 females) participated in the study (Mean age = 33.7 years, SD = 10.0). Experiments were conducted according to ethical guidelines approved by the Monash University Ethics Committee.

2.2. Apparatus and task

Participants wrote the word “minimum”, without dotting the “i’s”. This word was chosen as it has been recommended in neurological assessments, being identical in most European languages and not carrying any emotional tone (Lakke, 1990). Participants wrote upon a Smartboard (DViT 3000i; Smart Technologies, Calgary, Canada). This was a vertically oriented, touch sensitive screen that was 136 cm by 101 cm and situated 95 cm above the floor. Coordinates of objects touching the screen (in the case of this experiment, the tip of the Smartboard marker pen) were detected by three cameras mounted in the corners of the Smartboard that sampled at 200 Hz. The marker pen was 3 cm in diameter, with a 0.5 cm diameter writing tip. There were 3 experimental conditions. Participants held the Smartboard marker pen on the screen, and in response to an auditory cue, participants were instructed to write the word “minimum” within a rectangle presented on the screen, using the Smartboard marker. The rectangle was of a constant 10 to 1 aspect and was either small (20 × 2 cm), medium (70 × 7 cm) or large (125 × 12.5 cm) size, depending on experimental condition. These sizes correspond to the recommended heights for writing to be visible at 5, 17.5, and 31.5 m and would be the sizes required for classrooms, small and large lecture theatres (Reynolds & Simmonds, 1982).

2.3. Design

This was a repeated measures design with all participants writing the word “minimum” at three different sizes (small, medium, large). The three writing-area sizes were presented in three separate blocks of trials.

2.4. Procedure

The task was demonstrated by the experimenter. Participants practiced producing the word “minimum” without dotting the “i’s” on lined paper at a comfortable size. Participants then performed the task at the required size upon the Smartboard. After 5 practice trials, there were 20 experimental trials. Order of presentation of size conditions was counterbalanced across participants, to control any practice and fatigue effects. To reduce any potential effects of practice within each experimental condition, the last ten complete trials were analyzed (Wright, 1993).

2.5. Analysis

The y coordinates were low-pass filtered (10 Hz cutoff) using a recursive, dual pass, second order Butterworth filter and double differentiated using a 9-point central finite differences algorithm to
produce velocity and acceleration functions (Teulings & Maarse, 1984). Automatic algorithms determined the length, duration, and slopes of writing strokes. Peak velocity, time to peak velocity, time from peak velocity to zero velocity were obtained for each submovement, and the numbers of zero crossings in velocity and acceleration functions were counted. This was done for every trial (ten trials for each of the three conditions) for each participant. Indices of handwriting quality determined from these measures, are described in the following paragraph.

To obtain estimates of stroke length and duration, writing strokes were segmented on the basis of maxima and minima in the \( y \) displacement function. The number of submovements required to produce a writing stroke, was determined from zero crossings in the \( y \) velocity function. An index of ballisticity was determined by dividing zero crossings in the \( y \) acceleration function by zero crossings in the \( y \) velocity function (Maarse, 1987). As larger values mean less ballistic movements, this has sometimes been called a dysfluency (Meulenbroek & van Galen, 1988) or force inefficiency (Phillips, Stelmach, & Teasdale, 1991) index. Signal-to-noise ratios have been suggested to compare the degree of invariance in handwriting (Teulings, Thomassen, & van Galen, 1986). Unfortunately the measure proposed by Teulings et al. (1986) has been criticized for producing negative values (Wann & Nimmo-Smith, 1990). As variability increases with the mean, an alternative signal-to-noise ratio was used that involved the mean of a stroke parameter divided by its standard deviation. A measure of the shape of the velocity profile (asymmetry ratio) for each submovement was obtained by dividing the duration of the deceleration phase of movement by the total time for that stroke (Flash & Hogan, 1985). Slopes of each writing stroke were obtained from the \( xy \) coordinates at which \( y \) displacement was at a minima or maxima, angles were measured in degrees from vertical (top for ascenders or bottom for descenders).

Each dependent variable was submitted to separate one-way repeated measures analysis of variance. Planned comparisons were used to determine differences between small, medium, and large conditions.

3. Results

Handwriting normally ranges from 5 mm to 10 mm in height. Representative (unfiltered) \( xy \) plots of handwriting at the 3 sizes can be seen in Fig. 1. There were significant changes in the size, \( F(2, 16) = 355.820, p < .001, \eta^2 = .98 \), of handwriting. Planned comparisons showed that the length of writing strokes in the small condition (\( M = 1.50 \) cm, \( SD = 0.37 \)) differed significantly from those in the medium condition (\( M = 5.05 \) cm, \( SD = 0.81 \)), \( F(1, 8) = 224.714, p < .001, \eta^2 = .97 \), and medium differed significantly from the large condition (\( M = 8.67 \) cm, \( SD = 1.09 \)), \( F(1, 8) = 218.292, p < .001, \eta^2 = .97 \). As the scaling of handwriting had clearly changed, it is of interest to consider the changes in the manner of production of these movements, as this may offer insights into the mechanisms responsible for size changes.

Although some studies have reported a constancy of timing over changes in size, there were significant differences in the duration of writing strokes, \( F(2, 16) = 28.988, p < .001, \eta^2 = .78 \). Planned com-

\[
\begin{align*}
\text{minimum} & \quad 10 \text{ cm} \\
\text{minimum} & \quad 10 \text{ cm} \\
\text{minimum} & \quad 10 \text{ cm}
\end{align*}
\]

Fig. 1. Representative unfiltered \( xy \) coordinates at the three writing sizes.
Comparisons showed that the duration of writing strokes in the small condition ($M = 168.11\, \text{ms}$, $SD = 22.24$) differed significantly from those in the medium condition ($M = 208.44\, \text{ms}$, $SD = 38.75$), $F(1, 8) = 17.691$, $p < .01$, $\eta^2 = .69$, and medium differed significantly from the large condition.

Fig. 2. Representative $y$ displacement, velocity, and acceleration functions at the three writing sizes.
(M = 225.30 ms, SD = 34.92), F(1, 8) = 7.122, p < .05, $\eta^2 = .47$. An average increase in stroke size of 480% was associated with an average increase of 34% in stroke duration, and this indicates that timing is somewhat stable, but is not constant over changes in scale.

An increase in size of writing could be achieved by lengthening submovements or increasing their number. Neither of these hypotheses were clearly supported. The numbers of submovements required to write the word “minimum” varied significantly with the size of the handwriting, F(2, 16) = 4.861, $p < .05, \eta^2 = .38$, indicating an increase in size is not simply achieved by increasing the length of each submovement. Nor was writing size increased by simply adding more submovements during writing. Participants required significantly more submovements in the small condition (M = 33.68, SD = 2.46) than the medium (M = 31.72, SD = 1.44) condition, F(1, 8) = 6.252, $p < .05, \eta^2 = .44$, but the medium condition did not require more submovements than the large (M = 32.01, SD = 1.16) condition (F(1, 8) = 0.850, $p > .05, \eta^2 = .10$). This implies that the strategies adopted to produce the word “minimum” are changing with the size of the handwriting.

If changes in handwriting size invoked different oscillators, a change in writing slopes might be expected. There was a significant effect of writing size upon slope, F(2, 16) = 6.620, $p < .01, \eta^2 = .45$. Planned comparisons revealed that slopes did not vary significantly from the small (M = 27.69°, SD = 4.31) to medium conditions (M = 27.17°, SD = 3.66) (F(1, 8) = 0.307, $p > .05, \eta^2 = .04$), but did vary significantly from medium to large conditions (M = 24.66°, SD = 3.31), F(1, 8) = 12.289, $p < .01, \eta^2 = .61$.

The upsizing of writing was associated with changes in the kinematic structure of writing strokes. The number of accelerative and decelerative impulses also varied significantly, F(2, 16) = 9.178, $p < .01, \eta^2 = .53$. Participants required significantly more accelerative and decelerative impulses to produce the larger sized words (M = 60.06, SD = 13.73) than the medium size (M = 49.34, SD = 8.59), F(1, 8) = 16.598, $p < .01, \eta^2 = .68$, but the difference between medium and smaller words (M = 48.97, SD = 12.12) was not significant (F(1, 8) = 0.018, $p > .05, \eta^2 = .00$). This led to changes in the efficiency of writing strokes, F(2, 16) = 15.537, $p < .001, \eta^2 = .66$. The larger condition (M = 1.88, SD = 0.45) was significantly less efficient than the medium condition (M = 1.56, SD = 0.28), F(1, 8) = 13.939, $p < .01, \eta^2 = .64$, but the medium did not differ significantly from the small condition (M = 1.44, SD = 0.28) (F(1, 8) = 3.324, $p > .05, \eta^2 = .29$).

Kinematic analysis offers insights as to how writing strokes were produced. Representative y displacement, velocity, and acceleration functions may be seen in Fig. 2. There were significant increases across size conditions in both the duration of the accelerative, F(2, 16) = 26.399, $p < .001, \eta^2 = .77$, and decelerative phases of submovements, F(2, 16) = 27.263, $p < .001, \eta^2 = .77$. The relative proportions of time spent in accelerative and decelerative phases can be informative. The proportion of submovement duration devoted to deceleration was analyzed. Higher values of this measure imply greater periods of time spent in deceleration and a greater reliance upon terminal guidance. Writing size had significant effects upon the proportions of the movement devoted to deceleration, F(2, 16) = 4.671, $p < .05, \eta^2 = .37$. There was significantly more time devoted to deceleration in the small condition (M = 0.50, SD = 0.02) compared to the large condition (M = 0.48, SD = 0.01), F(1, 8) = 6.233, $p < .05, \eta^2 = .44$, but the difference was not significant for the medium condition (M = 0.49, SD = 0.01). With increases in writing size in this experiment, there was a reduction in the amount of time spent in deceleration and a greater proportion of time devoted to the acceleration phase of movement.

The signal-to-noise ratio allows comparisons between the degree of control of different stroke parameters. Where the signal-to-noise ratio is invariant, it implies that this aspect of the movement is tightly controlled and is a parameter that does not change as handwriting is rescaled. The signal-to-noise ratio for stroke duration varied significantly, F(2, 16) = 7.946, $p < .01, \eta^2 = .50$. The small condition (M = 4.03, SD = 1.81) varied significantly from the medium condition (M = 5.87, SD = 1.77), F(1, 8) = 8.584, $p < .05, \eta^2 = .52$, but the medium condition did not vary significantly from the large condition (M = 6.28, SD = 2.13), F(1, 8) = 0.622, $p > .05, \eta^2 = .07$. Stroke durations were more tightly controlled at larger sizes. The signal-to-noise ratio for stroke length varied significantly with changes in size of handwriting, F(2, 16) = 11.040, $p < .001, \eta^2 = .58$. Although signal-to-noise ratio did not vary between the small (M = 4.09, SD = 1.49) and medium conditions (M = 4.86, SD = 1.58), F(1, 8) = 3.954, $p > .05, \eta^2 = .33$, the ratio varied significantly between the medium and large conditions (M = 5.67, SD = 1.14), F(1, 8) = 6.94, $p < .05, \eta^2 = .47$. Stroke lengths were more tightly controlled at smaller
writing sizes. In contrast to the previous stroke parameters, the signal-to-noise ratio for stroke slope did not vary significantly over the three writing sizes ($F(2, 16) = 0.475, p > .05, \eta^2 = .06$). Values for small ($M = 1.61, SD = 0.12$), medium ($M = 1.71, SD = 0.30$), and large ($M = 1.67, SD = 0.38$) conditions were similar. It would appear that at larger writing sizes legibility requires a tight control over stroke slopes, and production of larger handwriting requires increases in accelerative and (to a lesser extent) decelerative phases of submovements to produce writing of a larger scale.

4. Discussion

The present paper considered changes in kinematic structure of writing strokes as a function of writing size. While normal handwriting ranges from to 5 to 10 mm in height, the present study examined increases in size commensurate with those observed when writing on blackboards. The data did not support the hypotheses that timing or length were invariant features, within a generalized motor program. Nor did the data support the hypothesis that larger movements were produced by the increase in a simple parameter of scale. Instead the lengths of writing strokes were altered by varying the number of submovements. When accomplishing the 5- and 8-fold increases in writing size participants prolonged the accelerative and to a lesser extent the decelerative phases of movement, while apparently maintaining tight control of stroke slopes. The number of submovements required when writing decreased and then tended to increase during the rescaling of handwriting movements, and the slope of handwriting varied implying changes in the oscillators employed to produce the writing movements.

The motor system can achieve “equivalent” output, albeit with different effectors, but this does not simply occur by changing a single scale parameter. The change in scale apparently required adoption of different strategies, as demonstrated by changes in the efficiency, segmentation, and timing of stroke trajectories. Whereas Schmidt (1982) might suggest that changing the size of handwriting would require the resetting of a single parameter, it is interesting that the number of submovements and kinematic structure of these writing movements varied, while a tight control was maintained over stroke slope. This suggests that spatial relationships (Teulings & Schomaker, 1993) rather than relative times (Viviani & Terzuolo, 1980) are invariant properties. Such constraints serve to control the legibility of writing output (Meulenbroek et al., 1996). Indeed some authors have suggested that the concept of motor constancy is misnamed. Meulenbroek et al. (1996) point out that the goal of writing is one of stimulus equivalence for purposes of legibility, while the motor system can flexibly attain this stimulus equivalence in a variety of ways.

Proponents of invariance of timing cite as evidence a constancy of response duration over changes in size (Wright, 1993). In the present study a 480% increase in stroke length was associated with a 34% increase in stroke duration, and others have also noted changes in response duration as size increases (Wright, 1993). Given the larger variations in size it appears that durations are somewhat stable, but durations are not invariant. Even though writing strokes were not performed in a constant time, the 1/3 power law linking tangential velocity and radius of curvature is also offered as evidence of timing invariance (Vinter & Mounoud, 1991). However, variations in the strength of the power law may be associated with movements of larger radius of curvature (Schaal & Sternad, 2001), and this has implications for an invocation of the power law to explain motor constancy (Phillips, 2008).

The present data are in keeping with an invariance of spatial features instead of timing (Teulings et al., 1986). Whereas there were significant differences in signal-to-noise ratios associated with stroke duration and length, the changes in the signal-to-noise ratio associated with slope were smaller and not significant. This may reflect the constraints placed upon the performance of this skill. Handwriting involves a static trace, such that spatial errors have clear implications for legibility (Meulenbroek et al., 1996; Teulings & Schomaker, 1993), but unlike some more dynamic skills (e.g., juggling) the writer can pause and make adjustment in midstroke if spatial error is at issue, without the reader being aware of the interruption. This is something that cannot be done with more dynamic skills.

The present data could still potentially arise from a simple reparameterization of a motor program, but if so, the observed differences could potentially arise from other factors. For instance, larger writing also requires greater differences in movement velocities that occur within the context of gravitational fields. Most previous studies of the constancy of handwriting have considered motion
in a horizontal plane. The transition from writing in the horizontal to the vertical planes occurs within the context of quite differential effects of gravity upon movements in left right and bottom top directions. For instance, Phillips, Triggs, and Meehan (2005) examined aiming movements in horizontal and vertical planes. Although there was no effect of graphics tablet orientation upon left/right movements, there were effects of orientation when movements coding the y axis were changed from horizontal (forwards/backwards) to vertical (upwards/downwards).

If a simple reparameterization was involved, we suggest the magnitude of rescaling precludes changing a simple scale parameter. The transition of writing from small to larger movements makes quite different demands upon musculature. Smaller movements may involve distal musculature, but larger movements require the involvement of proximal muscles, and this change in the muscles used may also contribute to the observed findings. It is simply not possible with hand and wrist to produce some of the larger writing movements studied. The present study considered strokes ranging on average from 1.5 cm to 8.67 cm, producing approximately a 6-fold increase in handwriting size. Others have examined 6-fold (Wright, 1993) and 15-fold (Rogers & Found, 1996) increases in writing size. For movements of such extent, it is likely that instead of a simple rescaling of a parameter, there is a shift from distal to proximal control of movements (Guiard, 1988). The simple non-linear changes in the number of strokes required may reflect phase changes associated with transitions from wrist to shoulder strategies during handwriting.

Dounskaia, van Gemmert, and Stelmach (2000) have observed that biomechanical factors, namely the joints used during writing, will influence writing movements, and thus a transition to larger movements may have implication for the motor system. Whereas there are distinct tendencies associated with the finger wrist system (Dounskaia et al., 2000), co-opting different oscillators for larger movements would also mean variations in biomechanical properties that might tend to influence the resulting movements. The present data demonstrate that the transition from smaller to larger writing involves a variety of different processes. Indeed, it is likely that quite different oscillators are involved as the writing movements are upsized, given that there are changes in the slopes of writing strokes. If the upsizing of handwriting involves a shift from distal to proximal muscles, and a change in oscillators, the lengthening of submovements to produce writing strokes appears to involve increases in the duration of the acceleration phase. Asymmetries between acceleration and deceleration phases have been observed in patients with dysmetric symptoms (Berardelli et al., 1996). Hypermetria (overshooting) is associated with disproportionate amounts of acceleration (Topka, Konczak, & Dichgans, 1998), whereas hypometria (undershooting) is associated with disproportionate amounts of deceleration (Manto et al., 1998). In the present experiment, increases in the relative duration of the acceleration phase was the means whereby movements were increased in extent (see Plamondon, 1995).

5. Limitations

It might have been desirable to have had a normal writing condition for comparison purposes in the present study. Unfortunately, writing on paper at normal size would have varied both size, orientation of writing surface, the writing implement, and the apparatus used to record the data, making comparisons difficult. Participants also had problems complying with the sizes of the guiding rectangles. Participants wrote within the rectangles rather than matching the rectangle exactly, but this approximates normal handwriting behavior when writing between the lines on paper.

6. Implications

The changes in the characteristics of larger writing strokes may have implications for handwriting recognition (Rogers & Found, 1996). Classroom sized computer displays are becoming more widely available, and are replacing the older computerized whiteboards. Such systems use standard Windows interfaces and character recognition, but such systems may not be robust to changes in character height (Araujo et al., 2006, 2007). The changes in the number of submovements suggests that changes in scale may lead to changes in segmentation and this may have implications for online signature processing algorithms (Araujo et al., 2006, 2007). In addition, the changes in stroke efficiency as a function
of size may have implications for detection of forgery, as line quality is likely to reduce as handwriting increases in size (Cha, Tappert, Gibbons, & Chee, 2004).

7. Conclusion

Kinematic analysis suggests that increases in the size of handwriting may not be accomplished by the simple upscaling of a single parameter such as time or scale. The number of writing strokes and their efficiency varied with writing size. The approximately 6-fold increases in writing size were apparently accomplished by varying the number and prolonging the durations of writing submovements (particularly the accelerative phase). Such variations in stroke production with writing size suggest that character recognition algorithms could be affected by changes in writing size associated with changes in the input devices employed.

References


