FOREPERIOD DURATION AND THE ANALYSIS OF MOTOR STAGES IN A LINE-DRAWING TASK*

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This study examines the effects of foreperiod duration and three motor variables on latencies and movement velocities of a line-drawing task. The motor side of the reaction process leading up to precise drawing movements was assumed to entail three stages, labelled motor programming, parameterization and initiation. In the present study we investigated the relationship between key variables to these motor stages and foreperiod duration. The results showed that number of elements, movement size and movement direction had independent contributions to choice reaction times of the line-drawing task. This finding is in accordance with our stage model. Foreperiod duration showed a significant interaction with movement size and additive effects with number of elements and movement direction. It may be concluded that the effect of foreperiod duration on the motor stages of choice reaction time may be regarded as a bypassing effect causing non-muscle specific variation of the level of motor activation as proposed by Sanders (1983).

Introduction

A number of experiments (Sanders 1977, 1980a; Sternberg et al. 1980; Spijkers and Walter 1985) suggest that the effects of foreperiod duration have their locus on the motor side of the reaction process. Naätänen and Merisalo (1977) and Sanders (1983) have suggested that these effects consist of fluctuations in the level of motor activation beneath, and with high levels of activation around, the ‘motor action limit’. Psychophysiological results support a motor activation hypothesis of time uncertainty by showing that (1) the amplitude of the late contingent negative variation (CNV) reflecting motor preparation (Loveless and Sandford 1974; Rohrbauch et al. 1976) is inversely related to foreperiod duration (Gaillard and Perdok 1980); (2) the

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effects of amphetamine interact with those of time uncertainty and appear to speed up motor rather than perceptual processing (Frowein 1981).

At the motor side of the reaction process Sanders (1980b) has proposed a Motor Programming and a Motor Adjustment stage. A 'structural' motor variable like response specificity - i.e. the extent the alternative responses have a common vector - would affect motor programming, while 'functional' variables such as instructed muscle tension, accessory stimuli and foreperiod would affect a more peripherally located motor adjustment stage. Sanders (1977) has pointed out that the combined effects of functional task variables cause an aspecific preparation of the subject while structural task variables affect the direction of the ongoing activity. The locus of both types of variables can be explored by means of the additive factor method (Sternberg, 1969). With this method it is possible to investigate the locus of effect of task variables by investigating their mutual relationships on choice reaction time (CRT).

A further partitioning of motor programming and motor adjustment was proposed by Van Galen and Teulings (1983) and by Van Galen et al. (1986). They formulated three stages of processing. The first stage (motor programming) retrieves an abstract motor programme from long term motor memory and loads this programme into a short term motor buffer (Henry and Rogers 1960). In a subsequent parameterization stage the abstract motor programme is adapted for real time execution by the substitution of parameter values for force and time. Finally, in the initiation stage, the programme with its parameter values are 'unpacked' (Sternberg et al. 1980) in such a way that the recruitment of an appropriate number of motor units and their locations can take place, dependent upon the actual anatomical and physical context of movement execution. Van Galen and Teulings (1982) presented experimental evidence for three motor stages by demonstrating that in a line-drawing task there were additive effects on CRT of (a) the number of elements of the task, (b) the spatial accuracy demands and (c) the anatomic effects of wrist versus finger movements. Van Galen and Teulings (1983) again found evidence for such a three-stage model of motor preparation in an analogous experiment with a letter writing task in which they varied the structure of the motor pattern, the size of the pattern and the anatomical system of the first element of the movement pattern.
To test Sanders' suggestions that foreperiod duration affects motor adjustment we explore in the present study the relation between the effects of foreperiod duration (150 and 1500 ms) and number of elements, movement size and anatomic effects of wrist versus fingers in a line-drawing task. A secondary aim was to reconfirm the results of the aforementioned studies concerning the relation of these key variables to our stage model. As repeatedly argued by proponents of the additive factor method, the results of a single experiment cannot be trusted, and in particular additive results should be repeatedly observed in order to gain credibility.

Given the further differentiation of 'motor adjustment' (Sanders 1980b) into the stages of parameterization and initiation (Van Galen and Teulings 1983) it is not clear whether foreperiod duration has its locus of effect on the parameterization stage, on the initiation stage or on both. However, if parameters for real time execution are set in a global manner, independently of the preparation of specific limbs and muscles which initiate the movement, it follows that aspecific activation of the motor system as a result of time uncertainty should affect the non-muscle specific parameterization stage rather than the muscle-specific initiation stage. Support for this hypothesis can be found in psychophysiological experiments on the effects of warning signals on preparing motor acts (Requin 1980; Brunia 1980; Haagh and Brunia 1984). These studies suggest two components of motor activation: (a) a general wave of activation spreading to the ipsilateral as well as to the contralateral side of the body, and (b) a more specific activation of the limb involved in the current action. However, the latter studies were performed with simple reaction tasks where it is possible for the subject to prepare a specific muscle group before the RT interval. In the present study we measured choice reaction times in which only a general activation of the muscular system is appropriate. We therefore assume that variation of foreperiod is related to a variation of the level of generalized activation.

It is known that size variations in writing tasks are foremost realized by force rather than by duration of the movement (Denier van der Gon and Thuring 1965). We therefore investigated movement velocity as a second dependent variable in this experiment because size variations in small line drawings affect movement time less than movement velocity. Van Galen and Teulings (1983) found that size, as a global performance variable in handwriting and drawing, is realized by an increased
level of activation in the neuromuscular system as a whole. It may be expected that foreperiod duration and size have a common locus of effect on the reaction process and therefore, according to the additive factor method, will have interactive effects on CRT.

In order to supply further evidence for a separate stage of muscular initiation which is independent of parameterization, we varied in addition to the aforementioned variables the anatomical character of the starting movement. In half of the trials the first drawing element was performed by a wrist movement. In the other half of the trials the movement was initiated by either extending or flexing the fingers.

Method

Task and apparatus

Subjects were seated at a table. At a position that was comfortable for drawing, a normal sheet of paper covered an XY digitizer (Calcomp 9240) with an RMS error of less than 0.2 mm. The drawing task was performed with the right hand with a normal ballpen which was connected to a PDP 11-45 computer through a flexible wire. To eliminate forearm movements, the forearm was placed and fixed to a cuff that was attached to the digitizer. The cuff could be adjusted to the subjects' forearm diameter (see Maarse et al. 1986). In front of the subject a rapid display screen (Vector General) was placed at a distance of 135 cm from the subjects' position. Subjects visually fixated this screen. The task consisted of copying as fast and accurate as possible with the pen a line drawing which was presented visually on the screen. At the start of a trial subjects held the pen in a starting position on the tablet which corresponded to the centre of the display screen. Then, a visual warning stimulus consisting of an asterisk was presented for 150 ms at the centre of the screen. After a foreperiod duration of either 150 or 1500 ms (constant within a block of trials) a visual imperative stimulus was displayed for 150 ms. In half of the trials the stimulus consisted of one line, starting at the centre of the screen and ending at one of the four bisection points of the sides of a virtual diamond (fig. 1). In the other half of the trials the stimulus consisted of two connected lines of equal length, one starting at the centre of the screen and ending at one of the four bisection points, the other starting at the bisection point and ending at one of the corners of the diamond. The movement size for single as well as double lines was indicated by the length of the displayed lines which was either 1 cm or 2 cm. The position of the subjects' arm and the starting position of the pen on the XY tablet were arranged so that lines in the lower-left to upper-right direction (and vice versa) would be drawn with only movements of the wrist while lines from the lower-right to upper-left direction (and vice versa) would be only drawn with movements of thumb and fingers. After presentation of the imperative signal pen movements were recorded with a sampling frequency of 105 Hz during a period of two
Fig. 1. Graphic display of stimuli and experimental conditions. S = centre of display and starting position of penpoint. One line starting at S and ending at one of the four bisection points of the sides of a diamond (1) indicated the movement direction of the first element. When a second line had to be drawn a second line was displayed starting at (1) and ending at one of the two corner-points (2) along the bisected side of the diamond indicating the movement direction of the second element. Required movement size was indicated by the size of the displayed stimulus lines (1 or 2 cm; equal lengths of lines in the 2-element task situation). Movements along the direction indicated by the dots consisted of wrist movements, along the direction indicated by the stripes consisted of finger movements.

seconds. During the sampling period immediate visual feedback of the drawing trace was given. At the end of the sampling period the feedback disappeared from the display, followed by a period of 1400 ms in which the subject replaced the pen at the starting position on the XY tablet. The replacing of the pen was done with the aid of immediate visual feedback of pen movements. A trial ended with a rest period of two seconds in which only the current penpoint position (the starting position for the next trial) was displayed. Movement latencies (RTs) and mean movement velocities were measured by means of an interactive computer analysis within the pattern of absolute velocities of the tip of the pen. Movement latency (RT) was defined as the time in ms between the onset of the stimulus and the start of the movement. Separate strokes were segments lying between successive points of zero velocity.

Subjects

Fourteen paid righthanded writing students served as subjects. Each subject was trained on the line-drawing task until a stable reaction time level was reached with a standard deviation of no more than 10% of the mean reaction time. The training consisted of a series of trials with short and a series of trials with long foreperiod durations. In both series all movement patterns were trained equally often. Training series with short and long foreperiod durations were counterbalanced across subjects.
Subjects were instructed to draw as fast and as accurate as possible the stimulus drawings presented as reaction signal. We tried to avoid confounding of accuracy and task variable effects by having no special tolerance limits with regard to movement size and movement direction during practice and experimental trials.

Procedure

The experiment consisted of two blocks of trials, each block containing three warm-up and 192 experimental trials. At random places within blocks nineteen catch trials (a plus sign on the display indicating that no movement was required) were interspersed. In one block the foreperiod between the visual warning and imperative signals amounted to 150 ms, which was 1500 ms in the other block. The two blocks were counterbalanced over subjects. Each block of trials had a different random order of experimental trials. Stimulus uncertainty varied on three dimensions: number of lines (one versus two lines), line size (1 versus 2 cm), and movement direction (wrist versus finger movements). Care was taken to counterbalance abduction and adduction of the wrist and flexion and extension of thumb and fingers in the one-element as well as in the two-element movements (see fig. 1). Data analyses consisted of analyses of variance. Cell entries for the analysis of latencies and movement velocities of the first element were the medians of 24 replications of each condition per subject (2 foreperiods $\times$ 2 number of lines $\times$ 2 line sizes $\times$ 2 movement directions $\times$ 24 replications making up 2 blocks of 192 trials). Similarly the movement velocities of the second element in the two-element movements were also analyzed by entering the medians of 24 replications into an analysis of variance (2 foreperiods $\times$ 2 line sizes $\times$ 2 movement directions $\times$ 24 replications making up 192 trials containing two elements).

Results

Errors and spatial accuracy

Errors were rare in this highly compatible line-drawing task. With short foreperiod durations 0.56% decision errors (i.e., wrong number of elements and/or wrong movement direction) occurred whereas this percentage amounted to 0.26% with long foreperiod durations. No anticipation errors (RT $<$ 100 ms) were observed.

Small and large stimulus drawings resulted in significant but small variations in movement distance of the first as well as of the second element. The mean movement distance of the first element was 1.305 cm in the small, and 1.686 cm in the large size condition ($F(1, 13) = 388.52; \ p < 0.01$). Mean movement distance of the second element was 1.319 cm in the small, and 1.583 cm in the large size condition ($F(1, 13) = 86.99; \ p < 0.01$). Movement distance varied little as a result of size instructions because (1) lines of 1 and 2 cm were presented on a screen 135 cm in front of the subject, and (2) no spatial tolerance limits for the subjects' performance were used. Size effects on movement distance were equal across experimental conditions except for a significant reduction in movement distance of the first element (0.074 cm) when this element was performed in the context of a second element ($F(1, 13) = 16.98; \ p < 0.01$).
CRT data

Table 1 summarizes the main effects and interactions of the CRT data. Number of elements had a significant ($F(1, 13) = 112.2; p < 0.01$) effect on CRT: on the average the 1-element task situation was 37 ms faster than the 2-elements task situation. Movement size had a small, but also significant ($F(1, 13) = 5.37; p < 0.05$) effect on CRT: the large figures were 5 ms faster than the small figures. The effect of movement direction was also significant ($F(1, 13) = 21.30; p < 0.02$): lines initiated by wrist movements had 7 ms shorter CRTs than lines initiated by finger movements. The latter two main effects seem to be rather small in relation to the temporal resolution with which the drawing movements were sampled (i.e., 105 Hz) and therefore have to be interpreted with care but the number of replications per cell ($N = 24$) as well as the spatial resolution of the digitizer (less than 0.2 mm) gave no reason to treat the effects as artifacts of the measurement procedure. The pattern of interactions shows that the effects of number of elements, movement size and direction were additive although the interaction between number of elements and direction fell just below the 0.05 significance level ($F(1, 13) = 4.18; p = 0.0593$). Fig. 2 depicts the effects of number of elements x movement size (upper-left graph), of movement size x movement direction (upper-middle graph) and of number of elements x movement direction (upper-right graph).

Foreperiod duration had a significant effect on CRT ($F(1, 13) = 34.95; p < 0.01$): mean CRT with a foreperiod duration of 150 ms was 321 ms; at 1500 ms this amounted to 365 ms. The lower part of Fig. 2 shows the effects of foreperiod duration and, number of elements (lower-left graph), movement size (lower-middle graph) and movement direction (lower-right graph). The analysis of variance showed no significant first order interaction of foreperiod duration with number of elements ($F(1, 13) = 0.16; p > 0.10$). Foreperiod duration and movement size significantly interacted ($F(1, 13) = 6.56; p < 0.03$), whereas the interaction between foreperiod duration and

<table>
<thead>
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<th>Effects</th>
<th>$F(1, 13)$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of elements</td>
<td>112.2</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Movement size</td>
<td>5.37</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Movement direction</td>
<td>21.30</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Foreperiod</td>
<td>34.95</td>
<td>&lt; 0.01</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Interactions</th>
<th>$F(1, 13)$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 x 2</td>
<td>0.92</td>
<td>&gt; 0.10</td>
</tr>
<tr>
<td>1 x 3</td>
<td>4.18</td>
<td>&gt; 0.05</td>
</tr>
<tr>
<td>2 x 3</td>
<td>0.48</td>
<td>&gt; 0.10</td>
</tr>
<tr>
<td>1 x 4</td>
<td>0.16</td>
<td>&gt; 0.10</td>
</tr>
<tr>
<td>2 x 4</td>
<td>6.56</td>
<td>&lt; 0.03</td>
</tr>
<tr>
<td>3 x 4</td>
<td>1.44</td>
<td>&gt; 0.10</td>
</tr>
</tbody>
</table>
Fig. 2. Averages of the median latencies for the line-drawing task as a function of: number of elements and movement size (upper-left graph), movement size and movement direction (upper-middle graph), movement direction and number of elements (upper-right graph), foreperiod duration and number of elements (lower-left graph), foreperiod duration and movement size (lower-middle graph), foreperiod duration and movement direction (lower-right graph).

movement direction appeared not to be significant \((F(1, 13) = 1.44; \ p > 0.10)\). While the main effects on CRT of movement size and direction were very small (5 and 7 ms, respectively) it appeared that the effect of movement size was so consistent that its interaction with foreperiod duration reached significance whereas the interaction between direction and foreperiod duration did not. No significant higher-order interactions were present.

**Velocity data**

Table 2 summarizes the main effects and interactions of the velocity data of the first and second element. The mean velocity of the first element \((V_1)\) was larger in the
Table 2
Results of analysis of variance on velocity data of 1st and 2nd element.

<table>
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<tr>
<th>Effects</th>
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<th>Second element</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(F(1, 13))</td>
<td>(p)</td>
</tr>
<tr>
<td>1. Number of elements</td>
<td>6.0</td>
<td>&lt; 0.03</td>
</tr>
<tr>
<td>2. Movement size</td>
<td>159.49</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>3. Movement direction</td>
<td>83.56</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>4. Foreperiod</td>
<td>1.85</td>
<td>&gt; 0.10</td>
</tr>
</tbody>
</table>

Interactions

<table>
<thead>
<tr>
<th>Interaction</th>
<th>First element</th>
<th>Second element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 x 2</td>
<td>1.46</td>
<td>&gt; 0.10</td>
</tr>
<tr>
<td>1 x 3</td>
<td>14.47</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>2 x 3</td>
<td>16.15</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>1 x 4</td>
<td>0.03</td>
<td>&gt; 0.10</td>
</tr>
<tr>
<td>2 x 4</td>
<td>0.09</td>
<td>&gt; 0.10</td>
</tr>
<tr>
<td>3 x 4</td>
<td>0.03</td>
<td>&gt; 0.10</td>
</tr>
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one-element than in the two-element task (V1: 6.767 and 6.519 cm/s respectively; \(F(1, 13) = 6.0; \ p < 0.03\)). Small line drawings were significantly slower than large line drawings (V1: 5.998 and 7.294 cm/s respectively; \(F(1, 13) = 159.49; \ p < 0.01\); V2: 6.740 and 7.516 cm/s respectively; \(F(1, 13) = 133.39; \ p < 0.01\)). Wrist movements performed as first element of the line-drawing task were significantly faster than movements of thumb and fingers as first element (V1: 7.210 and 6.071 cm/s respectively; \(F(1, 13) = 83.65; \ p < 0.01\)). As second element, however, wrist movements were performed significantly slower than finger movements (V2: 6.167 and 8.100 cm/s respectively; \(F(1, 13) = 38.12; \ p < 0.01\)). This last effect may account for the interac-

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![Fig. 3. Mean drawing velocity: of first element as a function of movement direction and number of elements (left graph), of first (middle graph) and second element (right graph) as a function of movement direction and movement size.](image-url)
tion of number of elements and wrist/finger movements ($F(1, 13) = 14.47; p < 0.01$) which was observed in the V1-data (fig. 3; left graph). Two other interactions, between movement size and direction were observed in the velocity data of the first and second element. In the first element movement size had a larger effect on the velocity of wrist movements than on the drawing velocity of finger movements ($F(1, 13) = 16.15; p < 0.01$ – fig. 3; middle graph). In the second element, however, movement size affected the drawing velocity of finger movements stronger than the drawing velocity of wrist movements ($F(1, 13) = 16.15; p < 0.01$ – fig. 3; right graph). Foreperiod duration did neither have a main effect upon velocity, nor any interaction with the other variables.

Discussion

RT-data

Our results show additive contributions of number of elements, movement size and movement direction to choice reaction times in a line-drawing task. Although these effects still need further verification because the interaction between number of elements and movement direction only fell just below the 0.05 level of significance, this outcome is consistent with the linear stage description of the motor aspects of drawing and writing as proposed by Van Galen and Teulings (1982, 1983). They found similar evidence suggesting three independent motor processing stages: (a) motor programming, i.e. the retrieval of an abstract motor programme; (b) parameterization, i.e. the substitution of parameters for force and time in the abstract programme; and (c) movement initiation, i.e. the recruitment of the required motor units of the anatomical apparatus. The distinction between motor programming and parameterization in the present model needs some further discussion. Motor programming is often conceptualized as the successive specification of movement parameter values of an abstract, non-motor representation into a format appropriate for force production (e.g. Kerr 1978; Rosenbaum 1980; Keele 1981; Kelso 1981; Klapp 1977; Schmidt 1982; Spijkers 1987). According to our view, motor programming is often referred to when the specification of kinematic movement parameters is investigated. Experiments concerning the preprogramming of movement parameters (Rosenbaum 1980; Zelaznik et al. 1982), i.e. the specification of parameter values prior to the reaction signal, may have contributed to referring to programming aspects rather than to parameterization aspects of movement control. On the contrary in the study
of complex motor behavior like speech, handwriting and gesture (Van Galen and Wing 1984) the term programming has got the meaning of an abstract, i.e. non-muscle specific, description of the movement pattern. For drawing (Van Galen 1980) and handwriting (Van Galen and Teulings 1983) it was argued that this abstract representation needs further parameters for size and speed, and a muscular realization appropriate for the current anatomical and biophysical context. It appears that 'motor programming' is an ambiguous term and its conceptualization depends upon the experimental design and variables under investigation. However, it should be stressed that the essential question is not the name of a stage but the probable number of independent stages responsible for the variation of reaction time as indicated by repeatedly found additive effects. The additive effects of number of elements and size found in this experiment as well as the additive effect of the structure of a movement pattern and spatial accuracy demands (Van Galen and Teulings 1983) indicate that the activation of the general structure of a movement and the specification of kinematic movement parameters are independent stages. In addition one might argue that motor programming as defined in the present model refers to the stage of response selection in which an abstract response code is activated as a result of stimulus-response alternatives or instructions which vary the compatibility of the relation between stimulus and response. The validity of the distinction between the motor programming stage defined as the retrieval of an abstract motor programme from long term motor memory after a response code is activated in the response-selection stage, and the parameterization stage, in which the specification of kinematic movement parameters takes place, needs further verification in experiments in which the combined effects of a wider range of response selection and motoric task variables (e.g., S–R compatibility, number of elements, element sequence, element size, spatial accuracy and movement direction) are investigated.

We found additive effects of foreperiod duration and number of elements which is consistent with Sanders' proposition that motor programming is not influenced by general preparation processes. The finding that the effect of foreperiod duration interacted with that of movement size but not with movement direction suggests that time uncertainty has its locus of effect on parameterization rather than on movement initiation. As mentioned in the introduction small size
variations in drawing and writing tasks are foremost realized by force rather than by duration of the movement (Denier van der Gon and Thuring 1965). Rosenbaum (1980) has shown that the preparation of movement size is even possible if the muscles with which the movement is performed are not yet known. Because time uncertainty is supposed to influence the overall level of motor activation (Naätänen and Merisalo 1977; Sanders 1983) interactions between effects of time uncertainty and movement size can be readily expected. Spijkers and Steyvers (1984) and Spijkers and Walter (1985) found additive effects of foreperiod duration and instructed movement velocity in reaction time experiments of discrete sliding movements of the arm. These results seem not to correspond with the interaction between foreperiod duration and movement size found in the present experiment. Spijkers and Steyvers (1984) showed furthermore that the effects of instructed velocity on reaction time disappeared when the required velocity was precued in advance of the reaction signal. In their experiments 'velocity' was manipulated by having the subjects produce accurately equidistant sliding movements of varying durations whereas in our experiments non-equidistant movements were required without specific spatial tolerance limits. The manipulation of required movement duration instead of movement distance might have led to presetting different movement strategies for the short- and long-duration movements and not to the actual setting of the force/speed parameter dependent upon the information in the reaction signal. In this way additive effects between the variable instructed velocity and the variable foreperiod duration might have been expected since the former variable relates indeed more to motor programming than to parameterization. Semjen et al. (1978) reported additive effects between foreperiod duration and movement extent in a pointing task. However, this effect fell just short below the 0.05 significance level ($F(6, 42) = 2.27$). Foreperiod duration contained four levels, 1, 2, 3 and 4 sec in their experiment and the interaction between foreperiod duration and movement distance appeared to be significant in a separate analysis with foreperiod durations of 1 and 2 sec only ($F(2, 14) = 4.34; p < 0.05$). A significant linear component of the interaction between foreperiod and target distance was also found in subsequent trend analyses. Their results indicated that reaction time differences between short and long movement distances increased as the duration of the foreperiod increased. These results correspond to the interaction between foreperiod duration and
movement distance found in the present experiment. Semjen et al. (1978) also reported a significant interaction between movement direction and foreperiod duration but since a pointing task was used it might be argued that in reaching to a specific target accuracy demands are confounded with aspects of movement direction and, as Van Galen and Teulings (1983) have shown, accuracy demands are referred to in our model as aspects of the parameterization stage.

Further the results showed that lines of 1 cm resulted in longer reaction times than lines of 2 cm. This may be explained by assuming that the preparation of antagonist activity to stop the pen has to occur within the RT interval in the case of 1 cm figures whereas this might be delayed in the case of 2 cm figures. The preparation of shorter lines seemed therefore more demanding than the preparation of longer lines. This could explain the direction of the interaction between foreperiod and size on CRT. In the case of the longer foreperiod duration the simultaneous preparation of the start and stop of a 1 cm line resulted in larger reaction times than with short foreperiod durations because general motor activation drops to a lower level with longer foreperiod durations. This process seems to occur independently from the muscles with which the movement is performed.

*Velocity-data*

Overall the velocity data confirmed the CRT effects. Drawing two lines did not only increase reaction time but also slowed down the velocity of drawing the first element. This finding is consistent with the view that motor programming is a process which partly continues during the execution of a task. It seems that during the longer RT for two-element figures programming is only partially performed. One might argue that ongoing programming activities during the execution of the task is in conflict with additive factor methodology. This argument would apply, however, if the degree of programming during the RT-phase would be left to strategic choices of the subject. In that case one would not expect reliable effects upon RT. With regard to the one versus two-element figures in our experiment we found a consistent effect of longer RTs for two-element figures. At the same time, however, it appeared that the ‘unpacking’ (Sternberg et al. 1978; 1980) of the final details of the second element of the drawing task seemed to occur concurrently with the real-time performance of the first element.
Comparable ‘unpacking’ effects have been found in earlier experiments with drawing and writing tasks (Van Galen and Teulings 1982, 1983; Van Galen et al. 1986).

Movement size significantly influenced drawing velocities. The finding of faster movements along longer trajectories is compatible with the finding of increased velocities until a maximum speed is accomplished in longer strokes in handwriting tasks (Denier van der Gon and Thuring 1965). We already assumed that in the case of the 1 cm figures antagonist activity to stop the pen has to be activated before the agonist reaches its maximum velocity. The latter finding is compatible with the outcome that the RT-data show longer RTs for the small figures. The interaction between number of elements and movement direction on drawing velocity showed that the proximal, single-joint, wrist movements are easier to perform as a first element followed by more distal, multi-joint, finger movements than as a second element preceded by such finger movements (Van Sommers 1984).

References


