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The effect of temporal and force changes on the patterning of sequential movements

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Summary. This article examines the programming of relatively long sequences of action with the control of sequential movements being effected through the use of a tapping task involving a sequence of five taps. Subjects were required to tap with their right hand at rates of 150, 200, and 250 ms. There were two conditions, with subjects being required either to increase, in condition 1, or to decrease, in condition 2, the force at one of the five tap positions (all five tap positions were examined), then return to the previous force level. Changes in timing resulting from variations in the force characteristics have previously been discussed in terms of changes in the organizational time required (Semjen, Garcia-Colera, & Requin, 1984). The current study breaks the intertap interval down into two separate components: the contact interval (finger in contact with the key) and the non-contact interval (interval preceding the tap). Although changes in the non-contact interval could be explained in terms of changes in the organizational time required, changes in the contact interval appeared to be a result of the mechanical changes in force.

Introduction

This article examines the serial organization of rapid movement sequences. As movement sequences increase in duration, how much planning or programming occurs in advance of their execution? Do all of the details have to be mapped in in advance or can some parameters be detailed during the on-going execution in a form of parallel or distributed planning? If such distributed planning occurs, is it a function of the duration, complexity, and/or speed of the movement sequence?

In general, motor-programme theory (Keele, 1981) implies that the entire sequence is planned in advance of movement execution. Typically, this advance planning has been identified through the high-speed production of relatively short movement sequences. The ability to maintain the fluency and control of relatively long-duration, serially organized movements, such as playing the piano, handwriting, and typing, cannot be explained solely in terms of traditional notions of advance planning. When sequences become longer in duration and contain a number of elements of varying complexity, then sequence planning and sequence execution are likely to overlap.

Semjen and Garcia-Colera (1986) have distinguished between two central representations for a movement sequence. First, there is an action plan that is descriptive and abstract in nature, and relates only to knowledge of what the response sequence should be. It is proposed that this plan alone can suffice when the execution rate is slow enough to allow for the step-by-step control of the elements in a sequence. For faster rates, an operational plan (motor program) that covers the whole sequence is crucial.

In recent reviews, Sternberg, Knoll, and Turock (1990) and also Keele, Cohen, and Ivry (1990) argue that the programming of rapid serial movements is hierarchical. Sternberg, Monsell, Knoll, and Wright (1978) have suggested that the complete motor act is made up of several subprograms, and that there are three processing stages that explain the latency and duration of rapid movement sequences. In the first stage, the appropriate subprogram is located through a self-terminating search. The second stage involves the unpacking of the constituents of the subprograms, and the third stage is the issuing of the commands to control the subprogram. The subprograms or modular units represent a level of analysis that is unrelated to the movements or muscles. Hence, the same representation can be decoded or interfaced to differing effector systems for execution, as in the case of handwriting with either hand, or even with the feet or mouth (Bernstein, 1947, cited in Keele et al., 1990).

It has been demonstrated that the amount of preprogramming of a sequence is a function of the number of elements in the sequence, such that the reaction time to

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initiate the sequence increases approximately linearly with the number of elements in the sequence (Sternberg et al., 1978). As early as Henry and Rogers (1960), it was conceived that the preparation of a program would take longer if the program was more complex. Henry and Rogers (1960) observed that reaction time would increase as the task changed from a finger lift to a reaching movement to a multiplanar arm movement. As the complexity of the movement sequence increases, so too does the reaction time to that sequence, presumably because of an increase in the time required to program the movement. One way to increase the complexity of a sequence is simply to increase the number of elements in the sequence (see Garcia-Colera & Semjen, 1988). The increase in reaction time tells us that sequence planning becomes more complex with an increase in the number of elements to be programmed.

Alternatively, the sequence length may be kept constant and complexity varied in other ways. Semjen and Garcia-Colera (1986) described a new experimental procedure whereby subjects were required to tap out a sequence with a constant number of taps. Complexity was varied by subjects being required to accentuate one of the taps. They found that if the sequence was made up of homogeneous elements, then reaction time was faster than if a stressed tap was required at one of the tap positions (heterogeneous elements). This difference in reaction time between homogeneous and heterogeneous elements was also observed by Klapp and Wyatt (1976) when subjects tapped to morse code. Sequences were composed of either short-key or long-key presses or of a mixture of the two.

Glencross, Piek, and Barrett (in press) modified the procedure used by Semjen and Garcia-Colera (1986) to produce a bimanual task that could be used to examine entrainment in a sequential task. Like the studies of Semjen and Garcia-Colera (1986) and of Klapp and Wyatt (1976), the reaction-time results suggested that the supposedly more complex plan required when heterogeneous elements are introduced (i. e., the stress tap) could not be completely completed before the response signal occurred and the execution commenced.

If it is not possible for all planning to occur during the interval between the go signal and the initiation of the sequence, then some of the planning must occur during the execution phase. For sequential movements, the interaction between advance planning and execution-time processing is important. Garcia-Colera and Semjen (1988) illustrate this as being most typical of longer sequences and perhaps reflecting either capacity limitation or time availability. Their own data favoured a time-availability explanation of distributed planning. When the timing for sequence execution is sufficiently slow, then the step-by-step organization of the sequence would be possible. There would be ample time between taps to satisfy any time-consuming processing demands. Evidence for execution-time processing comes from a lengthening of the intervals located just before or after a stressed tap (Garcia-Colera & Semjen, 1987; Semjen & Garcia-Colera, 1986). A slowing down of the movement is interpreted to be a result of higher processing demands in that particular part of the sequence. The subjects were presumably translating the force change into specific motor commands.

It has been argued that a change in the specification of the magnitude of force does not affect the time needed to organize the movement (Baba & Marteniuk, 1983; Ivry, 1986; Kasai & Komiyama, 1990). Rather, Baba and Marteniuk (1983) suggest that it is the timing of force that is the parameter of the movement that is organized in advance of movement execution. Using a ballistic forearm flexion, they found that although reaction time did not increase with a change in force while the duration of the movement was kept constant, there was a significant increase in reaction time when movement duration was increased and force held constant. Studies involving recordings from either single motor units (Tanji & Kato, 1973) or cortical cells (Smith, Hepp-Reymond, & Wyss, 1975) have also provided evidence that force and time are controlled separately.

Ivry (1986), using isometric contractions of the index finger, showed that although the reaction time did not vary as a function of force, timing variations, such as requiring the subject to maintain a response, produced consistent changes in reaction time. Ivry (1986) further pointed out that response duration and time to peak force increase more or less linearly with increases in force. Movements of greater force require both the recruitment of more motor units as well as increased firing of motor units (Desmedt, 1983).

Could it be that the increase in the intertap interval found by Semjen and Garcia-Colera (1986) before and after the stressed tap is a function of the force change itself? That is, the increase in time may be a result of the increased recruitment of motor units required for a stronger tap. In a study in which subjects were required either to increase or to decrease the force of one tap in a four-tap sequence, Semjen, Garcia-Colera and Requin (1984) found that there was an increase in the interval before and after the stress interval regardless of whether the tap was increased or decreased in force. They argued that this was evidence to suggest that the lengthening of the intervals could not be explained in terms of the mechanical factors related to a change in force.

In the current study, movement sequences will be investigated with an experimental procedure similar to that of Semjen and Garcia-Colera (1986). However, the timing between successive taps will be examined more closely: the intertap interval will be separated into the contact interval (time on the key) and the non-contact interval (time between successive taps). The purpose of this analysis is to determine whether the changes in timing found with the changes in force are a result of additional organizational requirements or simply a function of the force change itself.

A second issue to be investigated relates to the level of force. Real skills may require an accentuation of force or a reduction in force (e. g., "piano" vs. "forte" in playing the piano). Are force changes (increasing or decreasing) from the base-line level achieved with the same facility, as in tuning up or tuning down the gain, or does a reduction in force involve a change in the serial organization of the agonists and the antagonists, as the early work of Vince and Welford (1967) suggested? This will be investigated by the subjects being required either to accentuate a tap (as

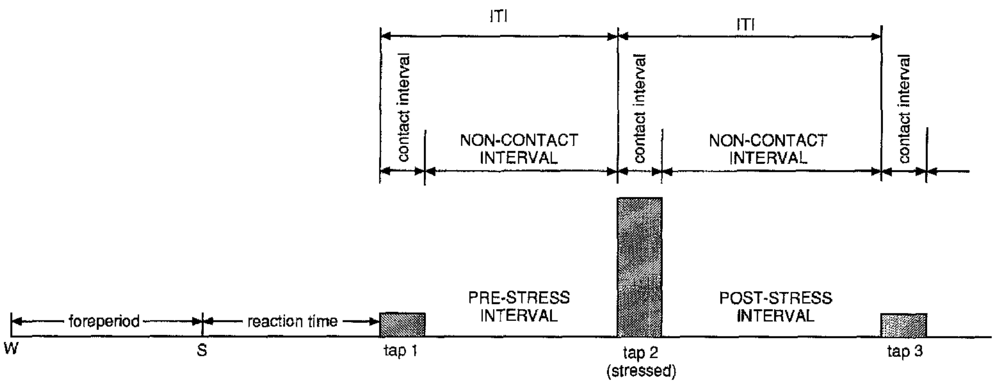

Fig. 1. The timing sequence for a typical response trial in which subjects are required to stress Tap 2 (W = warning signal, S = response signal, ITI = intertap interval)

in the earlier studies) or to attenuate a tap. The different temporal patterns that develop as a result of these changes will then be compared.

Method

Subjects. Six male and six female (right-handed) subjects between the ages of 18 and 40 years participated in this experiment.

Task and apparatus. The task was to produce movement sequences by tapping on a circular key with the index finger of the right hand. The subjects were instructed to make brief staccato taps by hitting the key and releasing it immediately.

The apparatus consisted of a key 1.5 cm in diameter, connected to a strain gauge, which in turn was connected to a metal earthing plate fixed to the table top. Any contact with the finger and surface of the key triggered an electronic circuit, the output of which allowed the identification of the onset of the tap. Tapping on the key also activated the strain gauge. The force of each tap was measured as the average output voltage for the finger-contact key.

The strain gauge was attached to a Chendai PC (Model H-1020) via a transducer (Phihong model PP-30-1-2) and an analogue and digital input card. Multiple Tapping Project (MTP) software was implemented to control the events in the tapping sequences and record all measurements. The sequences were presented to the subject on an Ingersall visual display unit (19 x 24-cm; model 12/500 MG-SAA).

Design. A 3 × 6 × 2 × 5 repeated-measures design with factors of tapping rate, stress-tap position, force condition, and tap location was used. Three tapping rates were used: 150, 200, and 250 ms. Six stress tap conditions were employed: a no-stress condition, then a stress at Tap 1, 2, 3, 4, or 5, with each subject changing the force of the tap at each of these positions. Subjects were required either to increase the force for the specified tap (Accentuated force condition – A) or to decrease the force at the particular tap position (Diminished force condition – D).

Subjects were given four testing sessions which were held on consecutive days. Half the subjects were allocated at random to the accentuated condition in the first two sessions and to the diminished condition in the last two sessions. The reverse occurred for the other half of the subjects.

For each tapping rate, subjects were given the no-stress condition first. For this condition, there were 4 blocks of 5 practice trials followed by 15 test trials. The five stress-tap conditions were randomized, and presented after the no-stress condition. There were 3 blocks of 5 practice trials followed by 15 test trials. All factors were counterbalanced across the 12 subjects.

Procedure. The subject was seated facing the keys and the height of the chair was adjusted so that the forearm and palm of the hand were resting on the table top, with only the index finger extended just above the key. This position was adopted in order to control the musculoskeletal movements so that only the index finger should contribute to the realization of the movement sequences.

Each trial began with a "Ready" signal, displayed on the VDU and simultaneously supplemented with an audible click. Following the ready signal, there was a foreperiod of 1,000, 1,200, 1,400, 1,600, or 1,800 ms. These were randomly presented for each of the trials, and preceded the onset of a green light-emitting diode (LED) which represented the signal to respond.

Before the start of the block of trials, the tapping sequence for those trials was displayed on the VDU. Large (1 cm) and small (0.5 cm) squares appeared on the screen. The large square indicated that a change in force was required at this tap location. When the squares appeared on the screen, an audible tone occurred simultaneously at the required tapping rate, with a higher-frequency tone occurring when the larger squares appeared. The tapping sequence descended down the screen. The squares provided the subject with knowledge of the position of the tap that required a force change and the tapping frequency of the sequence. Subjects were instructed to initiate their response as rapidly as possible when the response signal appeared, but not to anticipate the onset of the signal.

Results

Four dependent variables were measured in this experiment:

1. *Average force.* This was the average output voltage for force exerted while the finger was in contact with the key.

2. *Intertap interval.* This was the interval between the successive taps, and was defined as the delay between the respective tap onset times. The intertap interval was subdivided into two components:

2.1. *Contact interval.* This measured the time that the subject's finger was in contact with the key.

2.2. *Non-contact interval.* This was the interval before the tap when the subject was not in contact with the key, measured for taps 2, 3, 4, and 5. (No such interval was present for Tap 1.)

Figure 1 indicates the timing involved for a given trial, and the measures recorded if subjects are required to stress Tap 2.

1. Average force

The average force exerted on each tap under each condition is shown in Figure 2. As was expected, there was a significant difference in the average force between the two force conditions, $F(1,11) = 5.58$; $p < .05$. It can be seen that the two conditions appear to be mirror images of each other.

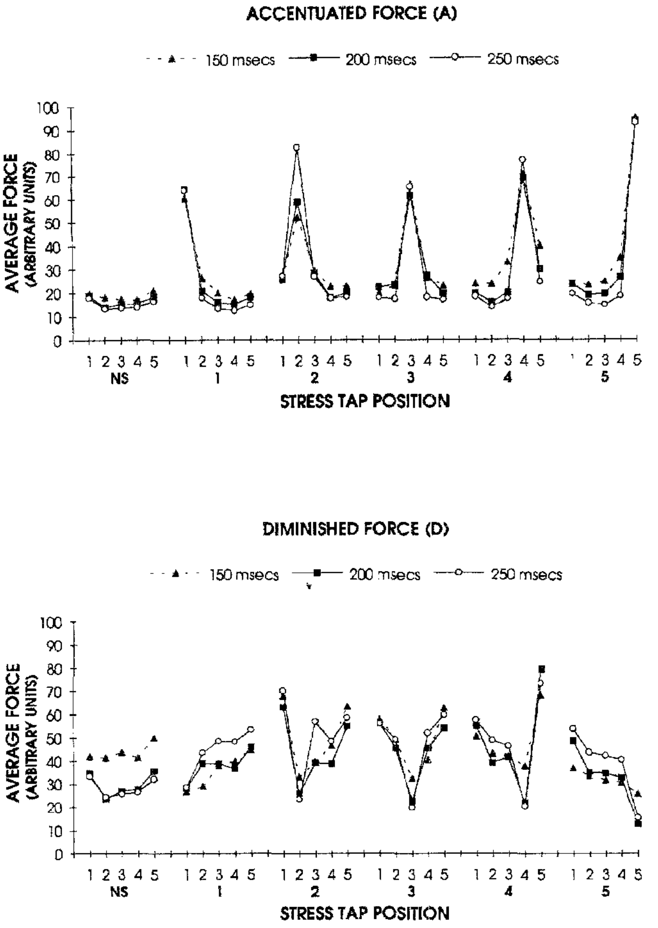

Fig. 2. Average force for the accentuated- and diminished-force conditions

That is, subjects did follow instructions and increased or decreased the force of the stress tap when required.

Examination of Figure 2 shows that when the subjects were required to diminish the force (Condition D), they appeared to set a higher level of force for the other taps rather than reduce the force level for the diminished force tap. The level for this tap was around the base level found in the accentuated force condition (A).

There was a significant main effect for tap position, $F(4,44) = 17.91, p <.01$. Semjen and Garcia-Colera (1986) found that the first and last elements of a sequence were accentuated more than the others. This pattern was present in the current study. For the no-stress conditions for both accentuated and diminished force, Tukey (1949) post-hoc analyses at the .05 level showed that for the slower tapping rates of 200 and 250 ms the average force for the first and last tap in the sequence was significantly greater than the middle three taps. For the fastest tapping rate of 150 ms, the average force for tap 5 was significantly greater than the other taps. This difference between the tapping rates may account for the significant interaction found between tapping rate and tap position, $F(8,88) = 2.24$, $p <.05$. No significant main effect was found for tapping rate.

There was a significant main effect for stress location, $F(5,55) = 5.69, p <.01$. Tukey (1949) post-hoc analyses, $p <.05$, showed that for the accentuated condition, the average force for the stressed tap was greater than all other taps in all conditions. The findings for the diminished-force condition, however, showed different effects under different conditions. Overall, the average force for the diminished tap was significantly less than for the other taps. However, there was still quite a pronounced increase in the force of the first and last taps for the diminished-force condition. This may explain the significant interaction between force condition and stress location, $F(5,55) = 5.10, p <.01$. There was also a significant interaction between stress location and tap position, $F(20,220) = 3.71, p <.01$, and between force condition and tap position, $F(4,44) = 7.87, p <.01$, and a three-way interaction between force condition, tap position, and stress location, $F(20,220) = 17.80, p <.01$.

Examination of Figure 2 suggests that for the accentuated-force condition, there was a progressive increase in the force of the stress tap as this tap moved from the beginning to the end of the sequence (Means: Stress Tap 1 = 62.7, Stress Tap 2 = 64.5, Stress Tap 3 = 64.2, Stress Tap 4 = 72.03, Stress Tap 5 = 93.5). This was also found by Semjen and Garcia-Colera (1986) and Semjen, Garcia-Colera, and Requin (1984). For the diminished-force condition, there appeared to be a decrease in force for the stress tap as the tap moved from the beginning to the end of the sequence (Means: Stress Tap 1 = 27.9, Stress Tap 2 = 27.4, Stress Tap 3 = 24.9, Stress Tap 4 = 26.6, Stress Tap 5 = 17.9), as was found by Semjen et al. (1984).

2. *Intertap interval (ITI)*

The essential features of the intrasequence timing for the two force conditions are shown in Figure 3. The tapping rate had a significant effect on the intertap interval, $F(2,22) = 205.65, p <.01$. This is to be expected, as the subject was required to maintain different speeds as specified by the tapping rates.

In their study on sequential tapping, Semjen and Garcia-Colera (1986) found unequal intertap intervals that were not necessarily dependent on whether a stress tap was required. They found that the first and last intervals were always longer. These results were also found in the current study. There was a significant main effect for tap position, $F(3,33) = 28.18, p <.01$. Tukey (1949) post-hoc analyses on the no-stress condition showed that for the slower tapping rates of 200 and 250 ms both the first and last intertap intervals were longer than the middle two intervals. For the fast-tapping rate of 150 ms, the first interval was slower than the other three. Once again, this difference between tapping rates may account for the significant interaction found for tapping rate and tap position, $F(6,66) = 3.55$, $p <.01$.

Semjen and Garcia-Colera (1986) further found that when a stress tap was introduced, the intervals located before (pre-stress interval) and after (stress interval) the stress were longer. In the current study, the introduction of a change in force level for one of the five taps did affect the temporal patterning of the movement, as was shown by a significant effect for stress location, $F(5,55) = 13.16$,

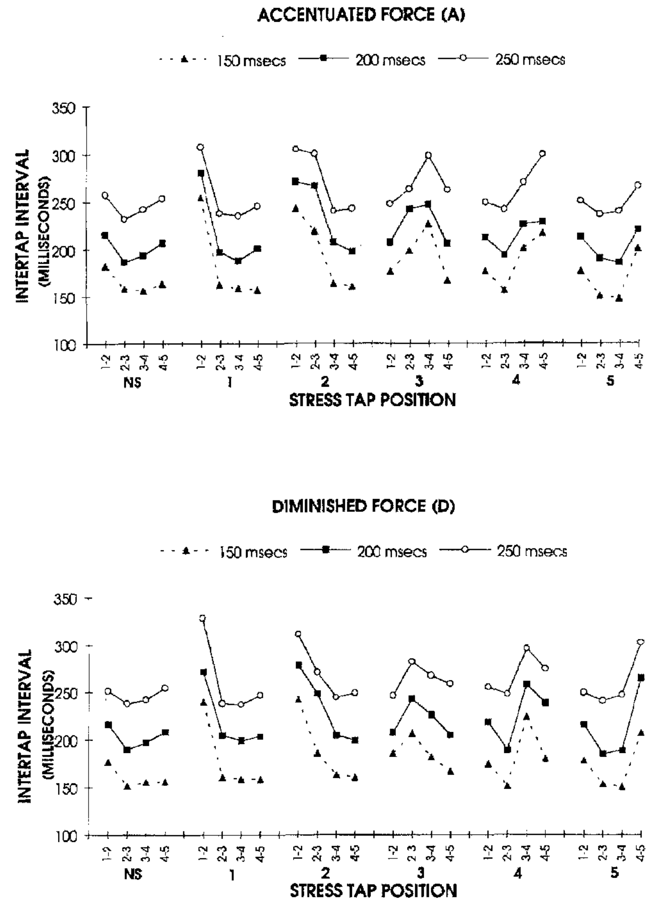

Fig. 3. Intertap interval for the accentuated- and diminished-force conditions. The four points at each stress tap location represent the tap intervals 1–2, 2–3, 3–4, and 4–5

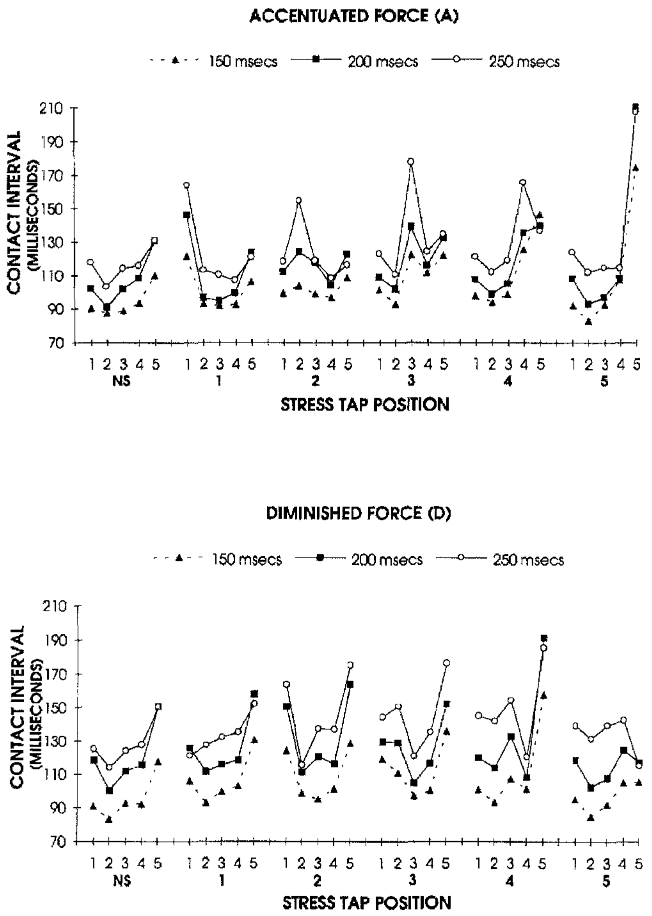

Fig. 4. Contact interval for the accentuated- and diminished-force conditions

p <.01. The significant interaction between stress location and tap position, $F(15,165) = 12.56$, p <.01, demonstrates that the degree of change in intertap interval for each tap is dependent on which tap is required to change its force level. From Figure 3 it can be seen that both the interval preceding the stress tap and the interval containing the stress tap were affected.

Is there a difference in the temporal patterning when the subject is required to accentuate the force of the tap (Condition A) rather than diminish the force (Condition D)? It appears that the answer is "no," as there was no significant difference found between these two conditions, F<1. However, we need to look at the interaction effects and post-hoc analyses to determine the overall effect of force on intertap interval. The significant interaction between the force conditions, the stress location and the tap position, $F(15,165) = 3.74$, p <.01, suggests that there may be some changes in the temporal structure for the two force conditions that are dependent upon the location of the stress tap. Tukey (1949) post-hoc analyses, p <.05, showed that for the accentuated-force condition, both the pre-stress and the stress intervals were longer than the other intervals. The stress interval was longer for all conditions, while the pre-stress interval was longer in all but a few conditions (namely, stress tap 3 at 150 ms and stress tap 4 at 250 ms). For the diminished-force condition, Tukey's post-hoc analyses showed that the pre-stress interval was longer than the other intervals (except the stress interval) for all conditions. However, the stress interval was longer at the tapping rate of 200 ms only for stress taps 2 and 3. This temporal structuring is seen in more detail by the separation of the intertap interval into the contact and non-contact interval.

2.1. *Contact interval.* The results for the contact interval, namely the time the finger is in contact with the key, are shown in Figure 4. A very different response pattern is evident for the contact interval compared with the intertap interval.

Once again, there was a significant main effect for tapping rate, $F(2,22) = 20.65$, p <.01. In general, the slower the tapping rate, the longer the finger is in contact with the key. This is consistent with the ITI results. The significant interaction between tapping rate and tap location, $F(8,88) = 4.33$, p <.01, suggests that this lengthening of the contact interval is not consistent over all tap locations, but varies with rate.

For ITI, the pre-stress interval as well as the stress interval were lengthened when the force was changed. The pre-stress interval contains the contact interval for the tap preceding the stress tap, while the stress interval contains the contact interval for the stress tap itself. As for the ITI,

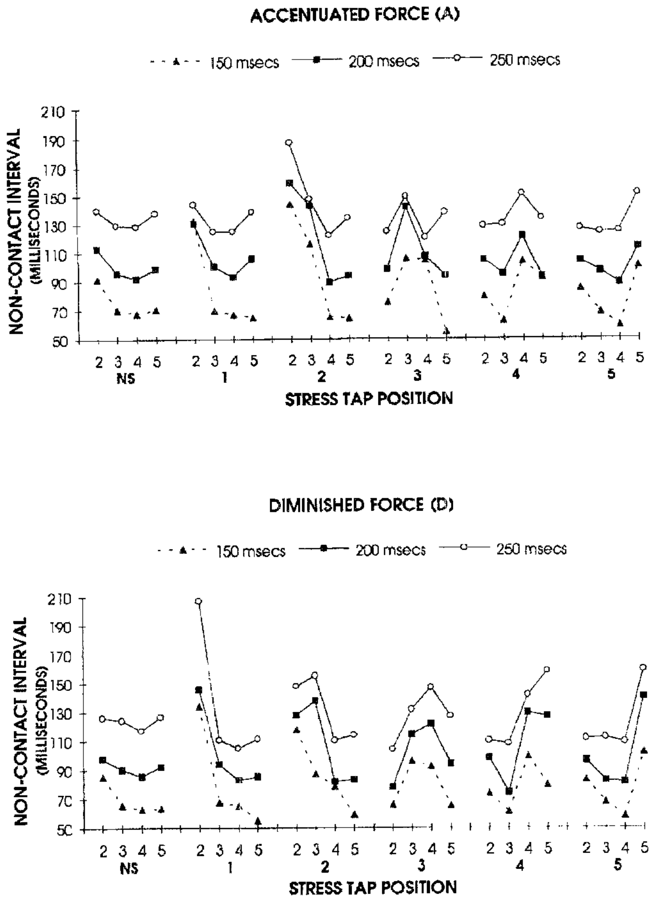

Fig. 5. Non-contact interval for the accentuated- and diminished-force conditions

the main effect of stress location was significant for the contact interval, $F(5,55) = 4.11, p < .01$, as was the main effect of tap position, $F(4,44) = 30.68, p < .01$. Furthermore, the interaction between stress location and tap position was also significant, $F(20,220) = 5.86, p < .01$. It can be seen that only the contact interval for the stress tap was affected by the change in force. The pre-stress tap was not significantly different. This was supported by the Tukey (1949) post-hoc analyses. Hence, the lengthening of the pre-stress interval for the ITI results could not be interpreted as a result of the finger being on the preceding key for a longer period of time.

Another difference between the ITI results and the contact interval is in the direction of the difference found for the stress tap. This was dependent upon the force condition. There was a significant interaction for both stress location and force condition, $F(5,55) = 4.60, p < .01$, and between force condition and tap location, $F(4,44) = 2.89$, $p < .05$, and a significant three-way interaction between force condition, tap position, and stress location, $F(20,220) = 11.45$, $p < .01$. A significant four-way interaction between force conditions, stress location, tap position, and tapping rate was also found, $F(40,440) = 3.65, p < .01$. When the subjects were required to increase the force (Condition A), the contact interval was longer for the stress tap than for the others. However, when the subjects were required to reduce the force of the tap (Condition D), then the stress tap was shorter than the other taps.

Overall, the results for the contact interval suggest that when more force is required, the finger is on the response key for a longer period of time, whereas when less force is required, the finger is on the key for a shorter period of time.

2.2. *Non-contact interval.* Figure 5 gives the results for the non-contact interval, that is, the interval preceding the tap, measured for taps 2, 3, 4, and 5. As in the other two temporal measures, the non-contact interval was dependent on the tapping rate, $F(2,22) = 56.57, p < .01$. The slower the tapping rate, the longer the non-contact interval.

Once again, there was a significant main effect for tap location, $F(3,33) = 14.45, p < .01$, and a significant interaction between the tapping rate and the tap location, $F(6,66) = 6.42$, $p < .01$). The Tukey (1949) post-hoc analyses, $p < .05$, for the no-stress condition again show an increase in the non-contact interval for the first interval (preceding tap 2) for all tapping rates, and an increase in the non-contact interval for the last interval (preceding tap 5) for the tapping rate of 250 ms.

Overall, the results for the non-contact interval are consistent with the findings for the ITI. That is, there appears to be a lengthening of the non-contact interval preceding the stress tap (included in the ITI pre-stress interval), and also a lengthening of the non-contact interval after the stress tap (included in the ITI stress interval), regardless of whether the subjects were required to increase or decrease the force of the tap. Although the main effect of stress position was not significant, $F(5,55) = 1.93, p > .05$, there was a significant interaction between stress location and tap position, $F(15,165) = 7.83, p < .01$. Tukey (1949) post-hoc analyses showed that the non-contact interval for the interval preceding the stress tap was significantly longer for all conditions, except for the stress tap 4 condition, at 150 ms for both accentuated and diminished forces, and at 250 ms for accentuated force, where post-hoc analyses were not performed, as the simple ANOVAs were not significant. Although the findings in Figure 5 suggest that the non-contact interval for the interval after the stress tap was longer than the other non-contact intervals in the sequence, the Tukey analyses showed this was not as consistent as the findings for the interval preceding the stress tap. The interval after the stress tap was more consistently longer in the diminished condition than in the accentuated condition, which may account for the significant three-way interaction between force condition, stress location, and tap position, $F(15,165) = 3.55, p < .01$ (also a significant four-way interaction of force condition, tapping rate, stress location and tap position, $F(30,330) = 2.37, p < .01$). There was no significant main effect for force condition, $F(1,11) = 1.99, p > .05$.

Discussion

Semjen and Garcia-Colera (1986) examined the temporal patterning of a sequential-tapping task by measuring the interval between the taps. They found a lengthening of the intervals before and after a stressed tap, and suggested that this was a result of additional organizational time needed when a tap of greater force was required. This was taken to be evidence for distributed planning of the movement, in parallel with movement execution.

In the current study, the results found for the intertap interval support the findings of Semjen and Garcia-Colera (1986). There appeared to be a lengthening of the first and last intervals of the tapping sequence, regardless of whether there was a stress tap or not, possibly as a result of the increased force exerted on the first and last taps. Semjen and Garcia-Colera (1986) referred to these force increases as "spontaneous" stress. There was also an increase in the intertap interval for the intervals preceding the stress tap and after the stress tap. However, closer examination of the temporal changes by means of a separation of the intertap interval into contact interval and non-contact interval suggests a different interpretation of at least some of Semjen and Garcia-Colera's (1986) findings.

Semjen and Garcia-Colera (1986) argued that the increase in the timing before and after the stress tap could not be a result of the production of more force in its mechanical aspect. Rather, the extra time is required for completing certain aspects of the "plan translation process" (p. 319). That is, additional processing time is required. Our findings for the contact interval, however, suggest that the increase in the interval after the stress is, at least partly, a result of the mechanical aspects of the force change. When subjects were required to increase the force of the tap, there was an increase in the contact period. When the subjects were required to decrease the force of the tap, the contact time was shorter. That is, the contact interval was a function of the force exerted on the tap.

If the contact time was less for the diminished force condition, why then was there a significant increase in the intertap interval for this tap? First, it was found that while there was a significant increase in the stress-tap interval for both force conditions, this effect was greater for the accentuated condition than for the diminished condition. Furthermore, the other component of the intertap interval for the stress tap, namely the non-contact interval, was significantly longer after the stress tap. This would account for the increase in the intertap interval for the stress tap. The extra time needed after the stress tap may be a result of the increased processing demands for changing the force back to the earlier level regardless of whether this is lower or higher.

The same result occurred for the non-contact interval preceding the stress tap. That is, regardless of whether the force was accentuated or diminished, the interval preceding this tap was lengthened. Because this change occurred for both force conditions, it cannot be attributed to any mechanical aspect of the force change, namely recruitment of motor units or increased motor-unit firing. In terms of the Sternberg et al. (1990) notion of hierarchical programming, the changes for the parameter of force are mapped in during movement execution. Our study supports this notion, and suggests that the lengthening of the interval preceding a tap with a change in force and of the one following the stress tap is a result of the temporal changes related to altering the force, and not the mechanical aspects of the force change itself. That is, these findings support the notion of Semjen et al. (1986) that the programming of longer movement sequences is distributed throughout the movement in parallel with movement execution. The parameter of force is mapped in as the movement progresses.

Ivry (1986) found that response duration and time to peak force increased more or less linearly with increases in force. This was supported in the current study, as the greater the force exerted, the longer the contact interval. Also, a decrease in the average force resulted in a shorter contact interval. There did not, however, appear to be a difference in the organizational time required for an increase, as opposed to a decrease, in the force. That is, it may be that there is no difference in the organizational time preceding an increase in the force of a tap from that of one preceding a decrease in the force of a tap. This contradicts the findings of Vince and Welford (1967) who suggested that "tuning-down" the gain (i.e., decreasing the force) requires a greater degree of organization. On the other hand, differences were found for the interval following a tap that had a force change. It must be remembered that the following tap must also undergo a change in force in order to return to the earlier force level. More time appeared to be needed to return the force to the higher level (i.e., the diminished-force condition) than to the lower level (the accentuated-force level). Further investigation is required on this aspect of the force change.

In conclusion, the current study has provided a means of investigating the temporal and force characteristics of sequential movements, by breaking down the intertap interval into two separate components. The findings support those of Garcia-Colera and Semjen (1988) and suggest that the planning of the movement continues during the movement execution (i.e., distributed planning). In the current study, the temporal pattern indicates that the parameter of force can be changed during the execution of the movement. Further investigation is required to determine how changes in the complexity of other parameters affect the temporal patterning of the movement sequence.

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