

## Strategies in the production of a 5 : 3 polyrhythm \*

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### Abstract

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The effect of part-task training (each hand separately) procedures was examined on the motor organization adopted by subjects in a bimanual task requiring the concurrent production of two different isochronous sequences. For both musicians and nonmusicians part-task training encouraging an integrated motor organization was more effective than part-task training emphasizing a parallel organization. Furthermore, in the performance of the bimanual task musically trained subjects, in both training conditions, adopted an integrated motor organization in which movements of the slow hand were subordinate to movements of the fast hand. These results suggest that the use of independent timing mechanisms for the two hands may not be possible in the performance of bimanual activities.

Polyrhythms require the simultaneous production of two conflicting but isochronous motor sequences. Most people experience great difficulty in coordinating the two hands in such tasks in which the two rhythms are not integer multiples of each other. Highly skilled musicians following extensive training, however, are able to accurately perform even the most complex polyrhythms (e.g., 5 : 3, 5 : 4).

There appear to be two general forms of motor organization that could be used in the production of polyrhythmic sequences. The first involves integrating initially separate activities into a higher order skill, so that it is no longer a dual-task situation. Deutsch (1983), for

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example, has argued that successful polyrhythm performance requires the development of an internal representation of the patterns as an integrated whole. The task then becomes a single sequence performed with two hands rather than two sequences performed by distinct hands. Alternatively, with practice, 'decoupling' of the hands may occur and the two limbs may operate in parallel, each producing a separate sequence of responses. Shaffer (1982), for example, has suggested that the rhythmic interplay between the hands, evident in the performance of highly skilled musicians, depends on being able to independently time the movements of the two hands.

Previous studies, however, have failed to find evidence for the operation of independent timing mechanisms in the performance of polyrhythms. Rather both skilled (musically trained) and unskilled subjects appeared to adopt an integrated form of motor organization involving the interleaving of the movements of the two hands (Jagacinski et al. 1988; Peters and Schwartz 1989; Summers et al. 1990).

The lack of evidence for the adoption of a parallel organization in studies of polyrhythmic tapping may be due to the use of subjects at relatively low levels of skill development. Another question of interest, which was the focus of this study, is whether learning the motor pattern for each hand separately before combining them would encourage the adoption of a parallel organization. This learning strategy, in fact, is recommended by some musical instructors.

In the present study we examined the effect of two part-task (each hand separately) training methods on the production of a five against three polyrhythm, with the right (preferred) hand taking the faster beat. One training scheme (Integrated) encouraged an integrated strategy, whereas the other (Separate) was designed to encourage the adoption of a parallel organization. The performance of musicians and nonmusicians was also compared. It was hypothesized that if a parallel organization is possible, then it would most likely occur in subjects with previous musical training.

## **Method**

### *Subjects*

Twenty-four right-handed subjects participated in the experiment. Twelve were experienced musicians, all having undergone five or more

years piano training. Six musicians and six nonmusicians were assigned to each training condition. Each subject participated in two sessions held on consecutive days.

### *Experimental task*

The experimental (transfer) task required subjects to tap out repetitively a 5 : 3 polyrhythm on two keys using the index fingers, with the right hand taking the faster beat. Each cycle of the polyrhythm was initiated by a simultaneous right hand and left hand response. Subjects attempted to produce the polyrhythm with a cycle duration of 1,500 ms. Thus the right hand was to tap every 300 ms, and the left hand every 500 ms.

### *Training conditions*

Before attempting the 5 : 3 polyrhythm subjects received part-task training under one of two conditions (Separate and Integrated). The Separate condition involved practice at producing the intervals for each hand independently (i.e. each right hand cycle = 5 intervals of 300 ms; each left hand cycle = 3 intervals of 500 ms). Subjects practised one hand and then the other until criterion performance was reached (see Procedure). The Integrated condition also involved separate hand training, but in this condition each single hand cycle was initiated by a simultaneous left- and right-hand response. Thus subjects in Integrated condition practised a 5 : 1 and a 1 : 3 rhythm. The two training conditions also differed in the instructions given to subjects prior to attempting the transfer (5 : 3) task (see Procedure).

### *Procedure*

#### *Day 1 – Training phase*

The aim of the training phase was to train subjects to produce the intervals for each hand independently with a high degree of accuracy. Three different response tasks were used in both training conditions.

(1) *Synchronization*. Subjects attempted to synchronize their taps to a sequence of pacing tones presented through headphones. The frequencies of the tones were 1100 Hz for the right hand sequence and 800 Hz

for the left hand sequence. To emphasize the cyclic nature of the task, the first tone in each single hand cycle was accented. Each trial consisted of 17 cycles of a single hand pattern. The synchronization task was used primarily to illustrate the required tapping rates for each hand (i.e. 500 ms, 300 ms).

(2) *Continuation*. After an initial period of synchronization (6 cycles) the pacing tones stopped and the subject continued tapping the pattern for a further 17 cycles.

(3) *Spontaneous*. This task was identical to the continuation task with the exception that the initial period of synchronization was omitted. Thus subjects were required to generate the pattern without external help.

In both training conditions subjects were first given a series of trials in the synchronization task. These were followed by continuation task trials when subjects indicated that they could imitate the sequence. The continuation task trials were continued until the subject produced three consecutive trials with an average deviation (obtained by averaging the absolute differences between the corresponding intervals in the response sequence and the 'target sequence') of 13 ms or less and a within-trial standard deviation (*SD*) for each interval in the sequence of 15 ms or less.<sup>1</sup> Once these criteria had been met subjects then practised the pattern under spontaneous task conditions. Spontaneous task trials were continued until the subjects produced two consecutive trials satisfying the above criteria. The same training procedure was used for both the right- and left-hand response sequences.

Subjects practised one hand for 9 trials (irrespective of the response task(s)), then the other hand for 9 trials and so on until criterion performance in the Spontaneous task was achieved. Half the subjects in each condition commenced training on the right-hand sequence and half on the left-hand sequence. Performance feedback, in terms of the mean interresponse interval (IRI) and standard deviation (*SD*) for each interval in a cycle, was displayed on an oscilloscope at the end of each trial throughout the training period.

### *Day 2 – Training*

If, at the beginning of day 2, subjects were unable to perform each single hand pattern at the criterion level, further training trials were

<sup>1</sup> These values were derived from pilot work.

given until criterion performance was achieved on 3 consecutive trials in the spontaneous task.

Subjects in the Separate condition only, were then given three practice trials (continuation task), on each single hand pattern, in which a simultaneous left- and right-hand response was introduced at the beginning of each cycle. This was done to ensure that subjects in this condition would understand the transfer task requirements.

### *Day 2 – Transfer*

Subjects in both conditions were told that they would now be required to perform the right-hand and left-hand patterns, on which they had trained, at the same time. Instructions to subjects in the Separate condition emphasized that the task involved separate sequences of responses for the two hands. Furthermore, subjects viewed a diagram of the overall polyrhythm but with the two response streams shown as unrelated sequences. Subjects in the Integrated condition, in contrast, were instructed to integrate the two sequences and were shown a diagram in which the response streams were presented as a unitary pattern.

Subjects in both conditions then listened for 1.5 min, without tapping, to the 5:3 polyrhythm presented through headphones. The frequencies of the tones were identical to those used in the Synchronization task during training.

After listening to the demonstration tones subjects attempted to generate the 5:3 polyrhythm under spontaneous task conditions. The test phase consisted of 10 trials, each trial continued until the subject had produced 136 responses (equivalent to 17 cycles of the polyrhythm). After the fifth test trial, the demonstration tones were presented for a further 1.5 min.

### *Data analysis*

For the transfer trials, the first 16 responses (equivalent to 2 cycles) in each trial were excluded from data analysis. Furthermore, only correct response cycles were analyzed. A response cycle was deemed correct if: (a) all eight taps were performed in the correct order, regardless of timing, and (b) the simultaneous response at the beginning of each cycle was made with no more than 20 ms separating the right- and left-hand taps, regardless of which key was depressed first.

## Results

### *Training phase*

All subjects were able to meet the specified criteria by the end of the training phase. Table 1 shows the mean number of training trials, across the three response tasks, required to reach criterion in the spontaneous task on day 1, and the mean deviation scores for the final two spontaneous task trials. In both training conditions more training trials were required for the left-hand pattern than the right-hand pattern. There was, however, no difference between the two training conditions in the number of training trials required for either hand ( $p > 0.05$ ).

### *Transfer phase*

None of the unskilled subjects in the Separate condition were able to successfully produce (see data analysis section) the 5:3 polyrhythm during the transfer phase. Three common response tendencies were observed among these subjects: (a) tapping the two hands in synchrony, (b) alternating the hands, and, (c) producing 5 taps with the right hand followed by 3 taps with the left hand. Two musically trained subjects in the Separate condition were also unable to perform the 5:3 polyrhythm. Both subjects produced regular beats with each hand but made six taps with the right hand so that every third response involved

Table 1

Mean number of training trials required to reach criterion level performance on day 1 and mean absolute deviation scores (in ms) for the final two training trials (spontaneous task) on day 1.

Training condition	Right hand		Left hand	
	Trials	Deviation	Trials	Deviation
<i>Integrated</i>				
Musicians	12.0	8.09	19.5	10.40
Nonmusicians	12.5	9.98	17.8	12.98
<i>Separate</i>				
Musicians	7.7	8.25	16.3	8.93
Nonmusicians	9.7	9.48	16.5	12.76

Table 2  
Absolute timing measures.

Training condition	Correct cycles	Cycle duration	Absolute deviation
<i>Integrated</i>			
Musicians ( $n = 6$ )	0.81	1538	31.94
Nonmusicians ( $n = 6$ )	0.37	2449	247.36
<i>Separate</i>			
Musicians ( $n = 4$ )	0.58	1495	42.84

a simultaneous right- and left-hand response. Data from these subjects were excluded from further analyses.

### *Absolute timing measures*

#### *Correct response sequences*

The maximum possible number of correct response cycles during the transfer trials was 150 (10 trials  $\times$  (17 - 2) cycles/trial). Although a higher proportion of correct cycles were produced by musically trained subjects in the Integrated condition than in the Separate condition (see table 2), the difference between the two training conditions was not statistically significant ( $p > 0.05$ ). A comparison between the two groups of subjects in the Integrated condition, however, showed that musicians produced more correct cycles than nonmusicians,  $F(1, 10) = 33.06$ ,  $p < 0.001$ .

#### *Cycle duration*

Also shown in table 2 are the mean cycle durations for correct response cycles. While musically trained subjects in both training conditions were able to meet the overall speed requirement (i.e. 1,500 ms), nonmusicians in the Integrated condition produced the 5:3 pattern at a much slower rate than required. The difference between the two groups in the Integrated condition was highly significant,  $F(1, 10) = 148.72$ ,  $p < 0.001$ .

#### *Accuracy*

As a global measure of how accurately the polyrhythm was produced a deviation score was obtained by summing the absolute time dif-

ferences between the corresponding intervals in the response sequence and the target sequence. The mean of these deviation scores was then computed across the correct cycles in a trial as a measure of absolute timing error (table 2). For musicians, subjects in the Integrated condition were more accurate than subjects in the Separate condition,  $F(1, 8) = 7.94$ ,  $p < 0.02$ . The difference between subject groups in the Integrated condition was also significant,  $F(1, 10) = 131.22$ ,  $p < 0.001$ .

### *Coordinating the two hands*

The main aim of this study was to determine whether the different training procedures would influence the way in which the two hands were coordinated in the performance of a 5:3 polyrhythm. One approach to this question is to examine the IRIs of within-hand taps. The 5:3 task required the simultaneous production of five regular beats with the right hand and three regular beats with the left hand. A parallel motor organization, therefore, would be indicated by the maintainance of regular beats within each hand sequence. An integrated organization, in contrast, would be suggested by a departure from regularity in the intervals produced by one or both hands, as subjects attempted to interlace the movements of the two hands.

To determine the organizational strategies adopted by subjects we examined the actual IRIs produced, converting each within-hand interval into a proportion of the total cycle duration, to correct for tempo differences between subjects, and then compared them to the target proportions (table 3). Musically trained subjects in both training conditions showed a similar response profile. These subjects maintained a

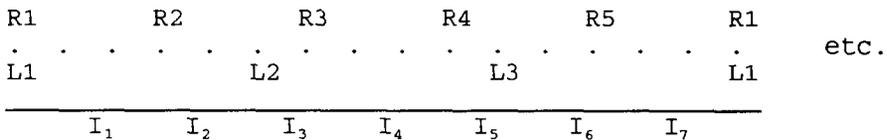
Table 3  
Mean proportions for right hand and left hand intervals.

Training condition	Right hand					Left hand		
	I <sub>1</sub>	I <sub>2</sub>	I <sub>3</sub>	I <sub>4</sub>	I <sub>5</sub>	I <sub>1</sub>	I <sub>2</sub>	I <sub>3</sub>
	0.20	0.20	0.20	0.20	0.20	0.33	0.33	0.33
<i>Integrated</i>								
Musicians ( <i>n</i> = 6)	0.20	0.20	0.20	0.20	0.20	0.32	0.38	0.30
Nonmusicians ( <i>n</i> = 6)	0.17	0.28	0.12	0.27	0.16	0.32	0.37	0.31
<i>Separate</i>								
Musicians ( <i>n</i> = 4)	0.20	0.20	0.20	0.20	0.20	0.32	0.39	0.29

regular series of taps with the right (fast) hand, but showed a large departure from regularity in the intervals produced by the left (slow) hand. In particular, there appeared to be a systematic tendency to shift the slow hand taps toward the middle of the fast hand interval in which they were contained.

Nonmusicians in the Integrated condition, in contrast, did not maintain a regular beat with either hand. The slow hand responses of these subjects showed a similar pattern to that exhibited by musically trained subjects – a lengthening of the second interval ( $I_2$ ). Large deviations from regularity, however, were also evident in the fast hand sequence. In particular, intervals containing a slow hand response ( $I_2$  and  $I_4$ ) were lengthened, whereas the interval between consecutive fast hand responses ( $I_3$ ) was shortened. This general pattern was exhibited by all subjects in the group. A comparison of the response profiles in the Integrated condition revealed a significant group (musicians versus nonmusicians) effect for all fast hand intervals ( $p < 0.05$ ) except  $I_1$  ( $p < 0.06$ ).

The general response profile exhibited by musically trained subjects suggests a form of integrated motor organization in which the movements of the slow (left) hand were interlaced with the movements of the fast (right) hand. Nonmusicians, in contrast, showed distortions of the intervals produced by both hands suggesting a somewhat different integration strategy. Further insight into the coordination of the two hands can be gained by examining the correlations between adjacent IRIs within a cycle of the polyrhythm. The sequence of responses required for the 5 : 3 rhythm is illustrated below:



Seven intervals between adjacent taps with either hand are created during one cycle of the polyrhythm. Estimates of the correlations between adjacent IRIs (normalized for each trial separately, to correct for any drift across trials, and then averaged) are shown in table 4. Of particular interest are the strong negative correlations for adjacent between-hand intervals (i.e.  $I_2, I_3; I_5, I_6$ ) exhibited by both musician groups. In fact, all musically trained subjects showed between-hand correlations less than  $-0.5$  (range  $-0.53$  to  $-0.90$ ). These negative

Table 4  
Correlations between adjacent IRIs within a cycle.

Training condition	Intervals					
	I <sub>1</sub> , I <sub>2</sub>	I <sub>2</sub> , I <sub>3</sub>	I <sub>3</sub> , I <sub>4</sub>	I <sub>4</sub> , I <sub>5</sub>	I <sub>5</sub> , I <sub>6</sub>	I <sub>6</sub> , I <sub>7</sub>
<i>Integrated</i>						
Musicians ( <i>n</i> = 6)	-0.31	-0.81	-0.10	-0.03	-0.88	-0.51
Nonmusicians ( <i>n</i> = 6)	-0.43	-0.25	-0.06	-0.04	-0.32	-0.51
<i>Separate</i>						
Musicians ( <i>n</i> = 4)	-0.25	-0.82	-0.03	-0.22	-0.89	-0.55

correlations are consistent with a bimanual coordination strategy in which subjects attempt to 'slot' the slow hand into the appropriate (i.e., R2-R3; R4-R5) fast hand intervals.

In contrast, only two between-hand correlations (both I<sub>5</sub>, I<sub>6</sub>) less than -0.50 were observed for nonmusician subjects (range 0.27 to -0.57). The correlation data, therefore, add further support to the view that musicians and nonmusicians adopted different strategies in the performance of the 5 : 3 task.

## Discussion

The present results show that training each hand independently does not lead to the adoption of a parallel organization when the two simple rhythms have to be produced concurrently. Rather subjects attempted to 'solve' the concurrent task problem by interleaving the movements of the two hands. Klapp et al. (1987) also found that whole-task training (both hands together), which encouraged an integrated and unified conception of the task, was a much more effective method of teaching a 3:2 polyrhythm than part-task training (each hand separately).

Musically trained subjects, in both training conditions, appeared to adopt a hierarchical form of integrated organization in which movements of the slow hand were subordinate to movements of the fast hand. A similar strategy has been observed in other studies of poly-rhythmic tapping, and was evident regardless of which hand took the faster beat (Peters and Schwartz 1989; Summers et al. 1990). This coordination strategy may relate to the role of attentional factors in the

performance of bimanual activities (Peters 1985; Peters and Schwartz 1989). That is, when faced with the task of executing two differently timed motor sequences at the same time, subjects focused attention on movements of the fast hand and the slow hand was interlaced with the fast hand.

Nonmusicians in the Integrated condition, however, appeared to adopt a different form of integrated organization to that exhibited by musically trained subjects. For these subjects both the fast and slow hand evidenced large deviations from regularity suggesting, perhaps, a linear chaining of the intervals within a cycle. Thus the timing of a response was cued by the preceding response in the sequence, regardless of hand.

None of the nonmusicians in the Separate condition were able to perform the 5 : 3 task. In fact, in their attempts to perform the dual-task, most subjects showed a tendency toward synchronization or alternation of the two hands. These tendencies are consistent with research, by proponents of the coupled oscillator model of bimanual coordination, showing that in-phase and anti-phase motion are stable modes of coupling the hands (e.g., Kelso and Schönner 1988). It is possible, therefore, that in the absence of explicit information regarding the temporal relationships between the two hands in the production of the 5 : 3 task, these subjects reverted to a 'lower' level of control and performance was dominated by motor interactions. The fact that musicians in the Separate group did not exhibit similar response tendencies suggests that one effect of musical training is the acquisition of strategies for integrating temporally incompatible motor sequences.

Finally, the present results suggest that a parallel motor organization may not be possible in the performance of bimanual activities. It may be, of course, that the acquisition of a parallel organization requires extensive practice on the whole-task (both hands together). However, in a recent experiment (Summers 1990) an integrated motor organization was observed even after eight days of practice (over 3,800 cycles) on a 5 : 3 polyrhythm.

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