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Part and whole perceptual-motor practice of a polyrhythm

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Abstract

An experiment is reported that investigated the effectiveness of receiving the perceptual experience of a bimanual, 2:3 polyrhythm during motor practice of the unimanual parts of the polyrhythm. Thirty-six participants were randomly assigned to one of three practice groups: One group practiced both parts of the 2:3 polyrhythm coincident with both pacing metronome tones (whole practice). Another group practiced each rhythm separately, hearing only the pacing tone for the corresponding rhythm (part practice). A third group also practiced each rhythm separately but heard pacing tones for both rhythms during practice (part/whole practice). Each group performed 25, 40 s learning trials for each rhythm; 900 ms intervals for the left hand, and 600 ms intervals for the right hand (a 2:3 polyrhythm). Transfer tests consisted of continuation tapping of the component rhythms, both unimanually and bimanually. Polyrhythmic structure, but not absolute timing stability, was facilitated when training was conducted in the presence of the whole perceptual experience of the task, even when part of the task was practiced unimanually.

Keywords: Perceptual; Motor; Learning; Polyrhythm; Part/whole practice

Coordinating the spatial-temporal motions of the upper limbs with a perceptual, pacing metronome is a natural and easy activity when certain constraints are met [17]. For example, coordination can be achieved with high levels of accuracy and stability when perceptual-motor synchrony involves either simultaneous or alternating patterns of finger tapping [19]. Coordination is also easy when the correspondence between the pacing metronomes is a simple harmonic ratio (e.g. 1:2, 1:3) [3]. Coordination is more difficult when the metronomes that pace each finger are offset in phase, even when in 1:1 correspondence (i.e. neither in-phase nor anti-phase) [19]. Coordination becomes extremely difficult when the correspondence between the metronomes does not follow a simple metric relation: the more complex the polyrhythm (from 2:3 to 2:5, 3:4, 3:5, 4:5), the more difficult the performance [3,13,15].

Perception of the auditory pacing stimuli also has an important impact on polyrhythm performance. Research has shown that two signals that were very different in pitch were perceived as separate auditory streams, whereas two signals that were close in pitch were perceived as an integrated auditory stream [2]. Further, polyrhythm performance is also affected by this auditory percept. An integrated stream used to pace a 2:3 polyrhythm produces better motor performance when compared when to separately perceived auditory streams [6,16].

Performance of polyrhythms usually improves with practice, depending on the form of the practice. Despite its heuristic appeal, one type of practice that results in much poorer improvement than expected occurs when the perceptual-motor timing goals corresponding to each hand are practiced unimanually (termed ‘part’ practice). For example, consider a 2:3 polyrhythm with a cycle duration of 1800 ms, in which the timing goals are two taps per cycle for the left hand (900 ms intertap intervals) and three taps per cycle for the right hand (600 ms intertap intervals) (see Fig. 1). A typical part practice strategy for learning this polyrhythm might involve a series of trials in which the timing stream for one hand is practiced, followed by practice with the other hand. Previous research has shown that this type of part practice is effective for learning the separate, individual timing goals for each hand. However, when the hands are required to perform their individual streams in a coordinated polyrhythm, there is very little or no transfer at all from this type of part practice [8,9,14].

One unaddressed issue in learning a polyrhythm is the contribution of perceptual information during part task

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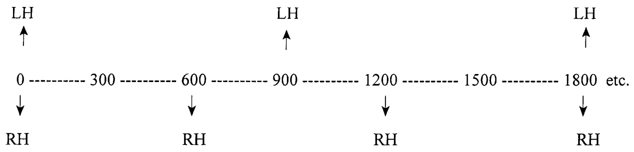

Fig. 1. A 2:3 polyrhythm with a cycle duration of 1800 ms. The timing goals are two taps per cycle for the left hand (900 ms intertap intervals) and three taps per cycle for the right hand (600 ms intertap intervals).

practice. Event coding theory, for example, provides a strong rationale for the contribution of perception in the ineffectiveness of part practice: codes that represent the execution of a motor act are learned in the context of the perceptual events that correspond with their execution [5, 11]. For each hand, in the production of a polyrhythm, an event code might represent five sources of information: (1) the production of the motor command at the designated time intervals (a tap), accompanied by; (2) the auditory sensory feedback resulting from the tap (e.g. a click), in the anticipation of; (3) an auditory pacing signal for that hand (the metronome signal), together in the context of; (4) the sensory feedback from the other hand's tap (click); and (5) its metronome pacing signal. When practiced in isolation (part practice), the learned unimanual rhythm for each hand is coded in terms of information sources 1–3 above. When practiced together (i.e. *whole* practice), each individual rhythm is learned in the context of all five sources of information. In terms of event coding theory, a part practice training regime would be ineffective for learning a polyrhythm because of diminished perceptual information represented in the code.

The purpose of the present study was to assess the effectiveness of part practice training in which the metronome pacing information for the other hand (information source #5, above) was also present during training. Transfer to the whole polyrhythm task by this group was compared to groups of participants that either practiced the whole task (the polyrhythm) or that practiced each hand in part without the metronome stream for the other (non-practicing) hand. Thirty-six volunteers (assigned at random to equal groups of 12), ranging in age from 22–28 years, served as research participants. All were right hand dominant.

The experiment was conducted in three phases on two consecutive days (phase 1 occurred on day 1 and phases 2 and 3 on day 2). The *part* practice group performed the timing stream for each hand separately, hearing only the pacing metronome tone for the corresponding rhythm. The *whole* practice group practiced both rhythms concurrently, hearing both guiding tones. The *part/whole* had some similarity to each of the other groups: this group practiced the rhythm for each hand separately (similar to the part group), but always heard the pacing tones for the entire polyrhythm (similar to the whole group). Practice that was specific to these groups was conducted in phases 1 and 2. Phase 3 was common to all groups.

In phase 1, participants in all groups performed 20 unimanual trials of 40 s duration with each hand. Half of the participants in the part group performed 20 trials, first hearing only the 900 ms tone, and tapping only with the left hand, and then an additional 20 trials hearing only the 600 ms tone, tapping with only the right hand. The other half performed in the reverse order. Participants in the whole group performed 20 trials, hearing both tones and tapping with both the left and right hands (thus, 20 trials for each hand). Participants in the part/whole group performed 20 trials hearing both tones but tapping only with the one hand, followed by 20 trials hearing both tones but tapping with the other hand (order counterbalanced). Phase 2 was conducted on the next day and was designed to reacquaint the participants with the task by performing five trials with each hand, following the same practice regime as in phase 1. Therefore, subjects in all practiced groups performed a total of over 1100 taps with the left hand and 1600 taps with the right hand during practice in the first two phases. In both phases 1 and 2, the metronome stream was provided for the entire trial. Phase 3 involved *continuation* trials, in which the metronome tone(s) were present only for the first 10 s of the trial, after which the participants were instructed to continue tapping the specified rhythm as accurately as possible for the remaining 30 s of the trial. All subjects, regardless of the practice group to which they were previously assigned, underwent the same procedures in phase 3, involving three types of transfer tests: (1) participants performed three continuation trials, tapping the polyrhythm bimanually (hearing both pace tones for the first 10 s); (2) three trials with the left hand, (the 900 ms tone being present during the first 10 s only); and (3) three trials with the right hand (the 600 ms tone being present for the first 10 s). The testing order was counterbalanced across subjects.

Participants tapped fingertip-sized microswitches that were secured to a table top. Two Mallory Sonalerts were powered to provide distinct signals of 1900 Hz and 4500 Hz, with cycle durations determined by a Lafayette four bank timer. Information from both the metronome streams and the keys were saved for later analysis using Windaq software.

The continuation data (non-paced cycles) for the phase 3 trials, common to all three groups, are reported. Two dependent measures were examined. First, the within trial standard deviations of the intertap durations were computed for each of the three trials per transfer test. The median value of the three trials was used in ANOVA. This measure provide an estimate of the absolute timing stability developed as a function of the different practice regimes. The second measure expressed the average performance of one hand as a ratio relative to the other hand. For a perfect performance to be achieved, the average performance duration of the left hand taps (900 ms) would be 1.5 times the average performance duration of the right hand taps (600 ms). This ratio measure estimates the scaling characteristic of the polyrhythm, regardless of absolute intertap durations (i.e. average left and right durations of 1200 and 800 ms, respectively, would also produce the 1.5 ratio).

ANOVA on the standard deviation data resulted in main effects for group, test, and more importantly, an interaction between group and test ($F_{2,33} = 7.85, P < 0.01$). The means for this interaction are illustrated in Fig. 2. A Tukey HSD revealed no differences between groups in the timing of the unimanual task. However, the whole practice group performed significantly better than both part practice groups in polyrhythm task performance ($P < 0.05$).

ANOVA on the performance ratio data also revealed a test main effect and, more importantly, an interaction between group and test ($F_{2,33} = 4.41, P < 0.02$). The means for this interaction are illustrated in Fig. 3. Again, no group differences are revealed in the unimanual test. In contrast to the stability data however, the performance of the polyrhythm was equivalent for the whole practice and part/whole groups, with both groups performing better than the part practice group ($P < 0.05$).

All forms of practice (part, whole and part/whole) were effective in the transfer performance of the unimanual task. In contrast, performance of the polyrhythm was dependent on the training regime. Whole task practice facilitated both the stability (SD) and rhythmic structure (ratio) of the polyrhythm. As predicted by event coding theory, subjects performed very poorly on the polyrhythm following part task practice during which only one sensory event was provided. Subjects in the part/whole group however, who were provided with the auditory streams for the entire polyrhythm during part task training, were as successful in producing the rhythmic structure of the 2:3 ratio as were the subjects who both practiced and heard the polyrhythm during training. However, these individuals were no better in maintaining the consistency of the intertap intervals than were the individuals who underwent part task practice.

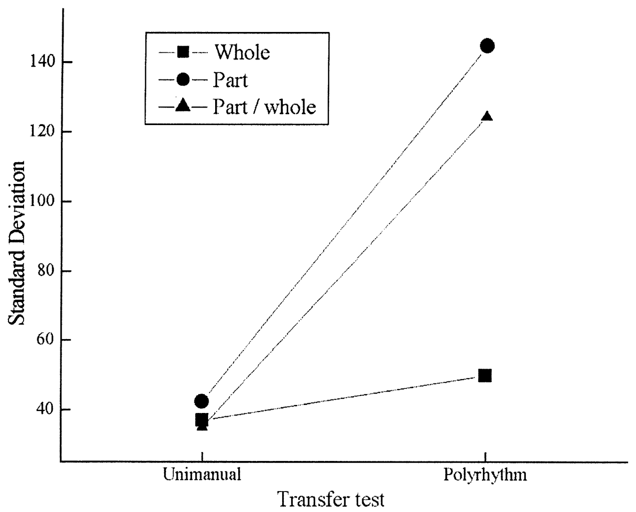

Fig. 2. Stability in transfer (standard deviation of intertap durations) of the unimanual and polyrhythm tests by the individuals groups following training under part, whole or part/whole practice conditions.

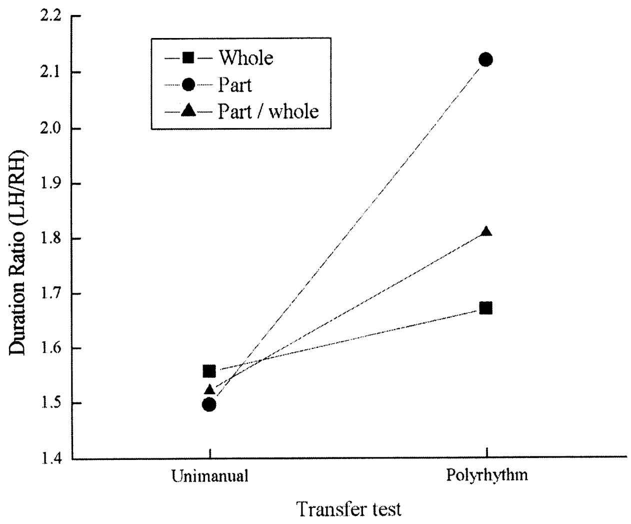

Fig. 3. Rhythmic structure in transfer (the ratio of interval durations produced by the left hand relative to the right hand) of the unimanual and polyrhythm tests by the individuals groups following training under part, whole or part/whole practice conditions.

A closer look at the ratio data for the part practice group reveals that the difficulty encountered in the bimanual test was the tendency to perform a simple harmonic rhythm rather than a polyrhythm. Nine of the 12 subjects performed a rhythm that closely resembled a 1:2 pattern. Performance by the other three subjects more closely resembled a 1:3 rhythm. These findings support previous research which suggest that, in the absence of a learned alternative, individuals tend to perform simple harmonic rhythms when attempting to perform polyrhythms [13,17]. It could be the case that subjects in the part practice group were perceptually aware that a 1:1 ratio was incorrect. The resultant corrective action to offset the limbs resulted in a slightly more difficult (though incorrect) 1:2 rhythm. Whether the individuals in this part practice group were perceptually aware that this pattern was incorrect and were incapable of further changes to the pattern, or whether they were perceptually unaware that this pattern was incorrect is unknown from these data, and await further research.

From an event coding perspective, these results suggest that supplementing part practice on the motor component with the auditory complexities of the polyrhythm facilitated one form of transfer but not another. Individuals in the part-whole group, provided with complete auditory information about the polyrhythm, could use this representation to facilitate performance of the rhythmic structure of the task. This result could have occurred because the auditory code of the polyrhythm was appropriate for pacing the basic structure of performance in transfer. However, in the absence of having practiced both motor parts of the task together, the intertap interval durations for each of the component rhythms was highly variable. In this instance, the complexity of the learned code was sufficient only for the basic rudiments of the polyrhythmic structure, not as a basis for consistent motor timing performance.

These findings are also compatible with both current and older theoretical perspectives that emphasize the importance of a referent of correctness in motor control. For example, the learning theories of Adams and Schmidt [1,12] emphasized that the establishment of a perceptually-based, referent of correctness was important in order to detect and correct errors in the absence of augmented feedback. The learning of perceptual information, especially auditory information [7], was considered to be an important component of learning a referent of correctness. A similar role for prediction and evaluation processes is also an important component of more recent, computational models of motor control and learning. Predictive information is a critical component of both forward and forward-inverse models [4,10,18] and it may well be the case that perceptually derived information provides a rich basis for motor learning within the architecture of these models.

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