

Contextual Interference: Single Task Versus Multi-task Learning

*Dana Maslovat, Romeo Chua,
Timothy D. Lee, and Ian M. Franks*

This experiment examined contextual interference in producing a bimanual coordination pattern of 90° relative phase. Acquisition, retention, and transfer performance were compared in a single-task control group and groups that performed 2 tasks in either a blocked or random presentation. Surprisingly, acquisition data revealed that both the random and control groups outperformed the blocked group. Retention data showed a typical CI effect for performance variability, with the random group outperforming the blocked group. Neither the random nor blocked groups outperformed the control group, suggesting interference of a second task may be as beneficial to learning as extra practice on the initial task. No group effects were found during transfer performance. Results suggest that random practice is beneficial for learning only one task.

Key Words: contextual interference, specificity, multi-task task learning

The influence of practice conditions on the acquisition, retention, and transfer of a motor skill has received considerable attention in motor learning research (see Brady, 1998; Magill & Hall, 1990, for reviews). Two variables that have been shown to influence how practice conditions influence learning are the *number* of tasks or task variations practiced and the *order* in which these tasks are practiced. Practitioners wish to know the most efficient and effective method to teach an individual a single skill or task in a closed environment. One option is to have the learner practice only the to-be-learned skill so that the practice environment closely resembles the retention environment. Another option is to have the learner practice many different skills in the hope that the increased difficulty of practice and interference from the other skills will enhance learning. Determining which option will best facilitate learning has important implications to practitioners.

D. Maslovat, R. Chua, and I.M. Franks are with the School of Human Kinetics at the University of British Columbia, Vancouver, BC Canada V6T 1Z1. T.D. Lee is with the Department of Kinesiology at McMaster University, Hamilton, ON Canada L8S 4L8.

Contextual Interference

One of the most powerful and frequently studied learning phenomena that arises from specific conditions of practice is known as the contextual interference (CI) effect (Battig, 1996; Shea & Morgan, 1979). The CI effect refers to the impact on learning caused by high interference practice conditions (e.g., random presentation of tasks) when compared to low interference practice conditions (e.g., blocked presentation of tasks). The typical finding has been that high levels of CI produce decreased acquisition performance yet increased retention and transfer performance relative to low levels of CI (e.g., Shea & Morgan, 1979). A common interpretation of this finding is that a more difficult practice environment, although initially detrimental to acquisition, results in enhanced information processing activities that ultimately benefit learning, as seen in tests of retention and transfer.

Two specific theoretical arguments have developed this enhanced information processing argument: the elaboration view (Shea & Zimny, 1983) and the reconstruction view (Lee & Magill, 1985). Briefly, the elaboration view suggests that random practice allows the learner to better remember the movement patterns to be learned because of more distinctive and elaborate processing. This enhanced processing occurs because of comparisons between the multiple tasks that are stored in short-term memory. Alternatively, the reconstruction view argues that random practice causes the learner to forget the processing activity carried out on the previously performed trial of a particular task, thereby requiring that the learner reconstruct the “action-plan” for the task on the next practice trial. This processing activity required by the reconstructions results in a more detailed and permanent memory representation of the task, thus benefiting performance in retention and transfer.

The typical CI paradigm involves the learning of multiple tasks (usually three or more) by two or more groups of individuals who practice different orderings of the trials on these tasks (cf. Brady, 1998; Magill & Hall, 1990). This paradigm may be contrasted with other research investigations that have focused primarily on variability and specificity of practice.

Practice Specificity

Studies that have examined the effects of practice variability typically find that practicing a number of different task variations results in greater retention or transfer performance when compared to the effects of practicing only one task, often argued as due to a better developed movement schema for that task (Schmidt, 1975). In contrast, practice specificity suggests that maximal retention performance of a task is facilitated by practice conditions that mimic retention conditions (Henry, 1968). That is, if a learner is only interested in learning a single task, performed in a specific manner, then the optimal practice conditions would involve only that task. The reasons given for the learning benefits of practice specificity typically involve the similarities of skill context or processing requirements. Experiencing a task in a practice context that matches the test conditions as closely as possible should lead to better performance upon retention (Henry, 1968). Transfer-appropriate processing views (e.g., Lee, 1988) suggest that the similarity of cognitive processes

involved in practice, retention, and transfer may also account for the benefits of practice specificity. What is not clear, however, are the conditions, situations, task characteristics, individuals, and so on that would lead practitioners to adopt variable practice conditions (random or blocked) or specific practice conditions when trying to optimize the learning environment.

Contextual Interference Versus Practice Specificity

Some studies have examined the combined influence of CI and practice variability (Hall & Magill, 1995; Lee, Magill, & Weeks, 1985; Turnbull & Dickinson, 1986; Wulf & Schmidt, 1988). Others have compared the effects of single task versus multi-task learning (Shea & Kohl, 1990, 1991). The purpose of the present study, however, was to compare the effects of CI and practice specificity on the learning of a single task. For the acquisition of a single task, we sought to determine whether performance is maximized by practicing the single task only (as suggested by practice specificity views) or by interfering with the acquisition of that single task by practicing it together with another task (as suggested by the CI literature). It is uncertain whether the learning benefits of interference can be applied to the acquisition of a single task or if the CI phenomenon is limited to conditions in which multiple tasks are acquired. To determine whether interference is beneficial to learning, performance in high and low CI conditions must be compared to performance in which practice is undertaken solely on the single task. Such a comparison would provide a baseline for determining if interference actually benefited the learning of each task or if it is simply the case that high interference produced better performance than low interference when learning multiple tasks.

Three recent studies that investigated CI involved comparisons of participants performing a single task versus multiple tasks; however, none of these studies were designed to compare specifically single task performance to multiple task performance. In one of the first studies to use a control group, Lee et al. (1985) measured absolute constant error and variable error using a timing task. Participants either practiced four different timing tasks in a blocked or random order, or performed 4 times the number of trials of a single timing task (control group). The random group performed with lower variable error scores than either the blocked or control groups during a transfer task that required the learner to extrapolate to a timing goal that was outside the range of timing goals that had been practiced. However this experiment did not use any retention tests, and thus conclusions were limited to transfer effects.

A second study to use a control group was conducted by Del Rey, Xiaoying, and Simpson (1994). Participants practiced various key press patterns in either a blocked or random acquisition schedule or were assigned to a single-task control group that only practiced a single pattern. No differences in retention were found among the random group, blocked group, and control group. However, as the purpose of this study was to examine retroactive inhibition in a contextual interference paradigm, the control group only performed one third the number of acquisition trials, reducing the effectiveness of a comparison among random, blocked, and single-task control groups.

In a third study, Shewokis, Del Rey, and Simpson (1998) varied three speeds (slow, medium, and fast) in a coincident timing task, requiring participants to coincide the release and slide of a hockey puck over a target line with the illumination of the last lamp on a Bassin timer. Groups performed the task in either a random or blocked acquisition schedule or only performed the task at one of the speeds (i.e., three single-task control groups). Results from the retention tests indicated that at the slow speed, the blocked group was more variable and less accurate than either the random or control groups. No difference was found between groups for the medium and fast speeds. However, again the control groups only had one third the number of acquisition trials compared to the other two groups. Furthermore, the use of coincident timing with varying stimulus speeds may be considered practicing the same task with different task parameters—a situation in which the degree of contextual interference may be insufficient to lead to a CI effect (Goodwin & Meeuwsen, 1996; Magill & Hall, 1990; Wulf & Lee, 1993).

None of the three studies cited above involving a single task control group were able to determine if single task learning was facilitated by practicing a single task only or by interference brought about by concurrent acquisition of another task. Thus, the purpose of the present study was to compare CI and practice specificity to determine whether interference created by task conditions is beneficial for learning a single task. We compared performance of a bimanual coordination task during acquisition, retention, and transfer of a single-task control group to groups performing two tasks under either high or low CI practice schedules. A secondary purpose was to determine the effects of interference and practice specificity on transfer of the learned task. Although practice specificity would predict better retention performance in the control group, the views related to the CI effect (i.e., reconstruction or elaboration) would predict better performance in both the random and blocked groups in transfer tests due to the learning benefits gained by increased interference. In addition, a typical contextual interference effect showing poorer acquisition performance yet better retention and transfer performance in the random group relative to the blocked group was also anticipated.

Learning and Bimanual Coordination

Recently, many studies have involved the use of a bimanual coordination task to assess how coordination performance changes during practice (Amazeen, 2002; Fontaine, Lee, & Swinnen, 1997; Kelso & Zanone, 2002; Lee, Swinnen, & Verschueren, 1995; Swinnen, Lee, Verschueren, Serrien, & Bogaerds, 1997; Tsutsui, Lee, & Hodges, 1998; Zanone & Kelso, 1997). A bimanual coordination task is a particularly valuable task to use in the examination of motor learning issues. The natural, intrinsic bimanual coordination patterns of 0° relative phase (in-phase) and 180° relative phase (anti-phase) have been termed attractor states as they represent stable coordination patterns of the limbs that can be performed skillfully without practice (Kelso, 1984). Although it is well known and assumed that adults learn new tasks in the background of existing skills, many of the tasks used previously in motor learning studies do not readily lend themselves to the examination of what those existing skills might be and/or how they might influence the acquisition of a new skill. Since the existing skills in a bimanual coordination task are known

(i.e., stability at 0° and 180° relative phase), the influence of new learning on these existing skills can be examined before, during, and after the learning of a new task (Zanone & Kelso, 1992, 1997). Thus, the bimanual coordination task offers a unique window through which to view the learning process.

Learning of a new coordination pattern (i.e., 45° , 90° , and 135°) involves considerable practice and results in the establishment of a new attractor state (Fontaine et al., 1997; Lee et al., 1995; Zanone & Kelso, 1992, 1997). This change in coordination dynamics emerges from a competition between the intrinsic coordination tendencies and the to-be-learned pattern. The immediate effect of initial practice trials is to “break away” from the influences of these existing skills, before a new pattern can be established, then stabilized. Often participants learning a new pattern spontaneously adopt either the in-phase or anti-phase mode until the new attractor state has been strengthened through practice. This spontaneous phase transition is especially prevalent when cycling frequency increases (Kelso, 1984). The appearance of a new attractor state also appears to affect the intrinsic dynamics of the system, especially the anti-phase pattern. Recent studies have shown that acquisition of a new coordination pattern (i.e., 90°) appears to at least temporarily destabilize the anti-phase pattern (Fontaine et al., 1997; Kelso & Zanone, 2002; Lee et al., 1995; Zanone & Kelso, 1997) and produce an attractor at the unpracticed, symmetrical phasing pattern (i.e., 270° ; Zanone & Kelso, 1997). Thus it appears that the learning process may involve both stabilization and destabilization of various coordination states, resulting in a modification of the entire range (or landscape) of coordination capabilities.

To determine the changes to the entire range of coordination capabilities, studies of the acquisition of bimanual coordination patterns have usually employed the use of a “scanning run” (Zanone & Kelso, 1992, 1997; more recently, Hodges & Franks, 2000). This process typically involves requiring the participants to perform a variety of coordination patterns, sampled from the entire range of possible patterns, at various points in the learning process to systematically observe the participants’ coordination tendencies. The rationale for a scanning procedure is that it provides an indication of a performer’s coordination tendencies. Thus the experimenter can directly observe any changes to the learner’s spectrum of coordination patterns during the learning process and determine what has been modified or acquired as a result of learning. These inherent tendencies have been considered a learner’s attractor layout or coordination landscape (Zanone & Kelso, 1994).

The task chosen for the present experiment was a bimanual coordination task, in which participants produced a specific coordination pattern. This study examined the acquisition of a 90° bimanual coordination pattern, practiced with and without interference from a 45° pattern. Few contextual interference studies have employed the use of a bimanual coordination task but rather have involved relatively simple tasks such as barrier knockdown, anticipation timing, linear positioning, and so on (see Brady, 1998, for a full review). However, with the acquisition of simple, discrete tasks, the analysis of movement has typically been limited to examination in terms of changes in the end result of the movement rather than changes in patterns of coordination that produced those outcome changes (Tsutsui et al., 1998). Performance of bimanual tasks, assessed through the measures of the relative coordination between the limbs (e.g., relative phase),

have been used as a global descriptor of bimanual coordination capabilities and thus represent a quantifiable measure of performance changes during acquisition, retention, and transfer. Thus, examination of a bimanual coordination task gives one the opportunity to examine the acquisition of a new pattern of coordination throughout the learning process.

In addition to the acquisition of a new coordination pattern being influenced by the intrinsic dynamics and attractors the learner brings to the task, different coordination patterns may pose different problems and levels of difficulty for the learner. Based on research showing that, of the two intrinsic patterns, the in-phase (0°) pattern is more stable and preferred than the anti-phase (180°) pattern (see Kelso, 1995, for a review), Zanone and Kelso (1992, 1994) predicted that patterns closer in relative phase to 0° would be more difficult to learn than those closer in relative phase to 180° . That is, the stronger in-phase attractor would be more difficult to overcome and thus would exert a stronger negative influence on learning a new pattern. Relative to this experiment, this prediction would suggest that the 45° task might be more difficult to learn than the 90° task. However, as the 45° task is only functioning as a secondary, interfering task, the comparative difficulty should not affect the experimental results. In addition, other studies (i.e., Fontaine et al., 1997) have not supported Zanone and Kelso's prediction, as they found no difference in learning a 45° pattern versus a 135° pattern.

CI and Bimanual Coordination

Although most CI studies have involved relatively simple lab tasks (Shea & Morgan, 1979), one study has examined if the CI effect can be expanded to bimanual coordination tasks. Tsutsui et al. (1998) had participants practice three novel bimanual coordination patterns (45° , 90° , and 135° relative phase) in either a blocked or random order. They found no difference in acquisition or retention performance when all three patterns were practiced on each of the 3 acquisition days but did find a typical CI effect when the blocked group practiced one pattern on each of the 3 acquisition days. Thus, it does appear that learning new bimanual coordination patterns displays CI effects. However, as with discrete tasks, the exact mechanism for why interference benefits learning remains unclear.

The present study further examined the effect of interference on the acquisition of coordination patterns. Rather than examining whether blocked or random practice is most beneficial for learning, this study examined the various practice schedule options for a learner wishing to acquire a single task. That is, if the goal of the learner is to perform one task, is it better to simply practice that task, or to provide interference from a second task (in either a blocked or random order)? As this experiment compared multi-task learning to single task learning, two tasks rather than three tasks (typically used by CI studies) were practiced by the blocked and random groups. Although this may have reduced the amount of interference in the blocked and random groups, it provided a better comparison to the single task control group, as the number of acquisition trials on the primary task (90°) was closer in number. That is, if three tasks were used by the multi-task groups, they would only receive one third the number of practice trials on the 90° task, thus making comparisons to the single task group less informative.

This experiment also differed from previous CI experiments in that participants were required to complete considerably more acquisition trials. The current study allowed for numerous practice trials and a minimum of 100 acquisition trials per task (200 for the single-task control group), whereas previous studies have allowed much fewer acquisition trials per task (i.e., 18 acquisition trials per task for Shea & Morgan, 1979; 45 acquisition trials per task for Tsutsui et al., 1998). These extra acquisition trials allowed for a deeper examination of the learning process and provided valuable information regarding the optimal practice schedule for a learner wanting to learn a single task.

Method

Participants

Thirty self-professed right-handed participants were randomly assigned to one of three groups (10 per group): (a) a two-task blocked acquisition group (blocked), (b) a two-task random acquisition group (random), and (c) a single-task control group (control). Participants were inexperienced with the task and were naïve to the purpose of the experiment. The study was conducted in accordance with the ethical guidelines of the University of British Columbia. All participants received a remuneration of \$5 per session (for a total of \$15) and a completion bonus of \$15. Participants were also informed that the best performer in the group would receive a performance bonus of \$50.

Apparatus and Task

A schematic of the apparatus is illustrated in Figure 1.

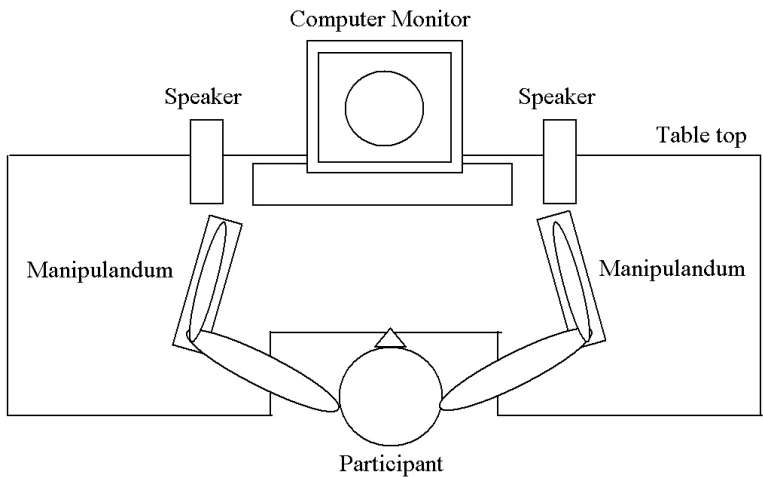


Figure 1 — Schematic display of apparatus set-up and design including location of monitor, speakers, and manipulanda.

Participants were seated in front of a color monitor (VGA 640×480 pixels) measuring 27 cm in width and 20 cm in height (Zenith, Model #ZCM-1490). On each side of the monitor was a lightweight manipulandum that participants used to perform flexion-extension movements in a horizontal plane about the elbow joint. Participants' arms were positioned such that the elbow joint was aligned with the axis of rotation and the hands were placed palm down on adjustable metal plates. The middle finger was secured between two vertical pins, and Velcro straps secured the forearms and hands. Amplitude was specified by computer feedback and markers on the table, specifying *in*, *mid*, and *out* positions for each arm. The required movement amplitude was 40° from the *in* to the *out* markers. A 40° movement translated to a 15-cm movement on the computer screen. Angular position was recorded using two optical encoders (Dynapar, E20-2500-130), one attached to the shaft of each manipulandum. Three-axis Quadrature Encoder interface cards (Advantech, PCL-833) were used to enable high-speed sampling of angular positions, giving a resolution of 1000 counts per revolution. Angular position was sampled at a rate of 1000 Hz. A computer motherboard was used to generate the audio metronome tones. The metronome signal was amplified by a speaker on each side of the monitor (Multi-Media, Model #EP-691).

The tasks involved the production of two bimanual coordination patterns using the two angular manipulanda. The movements with the manipulanda involved continuous flexion and extension movements about the elbow joint in the horizontal plane. By way of reference, when homologous muscles for both limbs flexed and extended simultaneously, the coordination pattern was described as "in-phase," or in 0° relative phase. When homologous muscles for both limbs flexed and extended alternately, the coordination pattern was described as "anti-phase," or in 180° relative phase.

Participants in this study either performed all trials on a single bimanual coordination pattern of 90° relative phase (left hand lagging one quarter cycle behind the right hand), or performed trials of two different bimanual coordination patterns of 90° and 45° relative phase (left hand lagging one eighth cycle behind the right hand). Augmented visual feedback was provided via a Lissajous figure projected on a computer screen, with participants' movement superimposed over a template (refresh rate 60 Hz). Specifically, movements of the right manipulandum produced horizontal movements of the cursor on the screen, while movements of the left manipulandum produced vertical movements of the cursor on the screen. Each complete cycle of movement by the participant produced one continuous plot over the Lissajous figure. The Lissajous figure for the 90° relative phase movement produced a circle (depicted in Figure 1), while the 45° relative phase produced an ellipse. Direction of the movement was indicated above the Lissajous figure by either the word "clockwise" with a right direction arrow or the word "counterclockwise" with a left direction arrow. A metronome (1 Hz) was used for all acquisition and retention trials, with participants instructed to complete a full cycle for each "beep" of the metronome. Speed was monitored for correctness throughout the experiment.

Experimental Design

Instructions. All participants familiarized themselves with the task apparatus and were provided with general instructions. These alerted the participants to the goal of the task—that is, to learn how to move the arms in such a way as to produce the pattern displayed on the computer screen. Participants were informed that concurrent online feedback would be displayed on the monitor. This involved a continuous trace of their movement pattern in the form of a Lissajous figure throughout the duration of the trial.

Participants were informed that each trial would last 12 s, and they should try to produce 12 full cycles in that period. Participants were informed that an auditory metronome would sound at the start of the trial, which would signal when to begin moving, and which would then “beep” every second after that (i.e., at 1 Hz). All participants were reminded to try and keep both their arms moving throughout the trial. Participants were allowed a maximum of four practice trials without a metronome or Lissajous template to familiarize themselves with the relation between the arm movement and corresponding visual feedback provided on screen.

Prior to the start of acquisition trials, all participants were given a minimum of 30 trials of experience with the task that was common to all groups (90° relative phase) to ensure a moderate level of experience with regards to bimanual coordination. The rationale for minimal experience level was to ensure participants had sufficient experience with the task such that interference would be expected to provide a benefit. Previous studies (Del Rey, 1989; Del Rey, Wughalter, & Whitehurst, 1982; Jarus & Goverover, 1999) have indicated that for inexperienced performers who are still trying to understand the movement, additional interference provided by a random task presentation may not provide any learning benefits and may actually hinder performance. Thus the positive effects of random practice may not be realized until some degree of expertise has been achieved. However, it is important to note that studies have shown the contextual interference effect with inexperienced participants using bimanual coordination (Tsutsui et al., 1998).

Group Assignment. Participants were randomly assigned to the blocked group, the random group, or the single-task control group. The blocked and random acquisition groups practiced two bimanual coordination patterns, 90° and 45°, in either a blocked or random presentation schedule, respectively. The single-task control group practiced a 90° pattern. The purpose of the single-task control group was to determine a baseline value of performance when only practicing one task, to be used as a comparison for the blocked and random groups.

Scanning. Scanning runs were performed for all participants prior to the beginning of acquisition trials (pre-acquisition), immediately following completion of the acquisition trials (post-acquisition), and immediately following the final day of testing (post-retention). Scanning trials required the individual to “track” two discrete, visual metronomes. Two squares (3 cm × 5 cm) were displayed at eye

level in the center of a black computer screen, aligned horizontally, 5 cm apart. These two squares served as visual metronomes, whereby each square flashed on (green) for 200 ms and off (black screen) for 800 ms at various phase relations. To manipulate relative phase, onset of the flash was controlled by a customized computer program that allowed for the production of different phasing patterns. Participants were asked to continuously flex and extend their arms between the *in* and *out* markers such that they synchronized peak flexion of each arm with the onset of the respective flashing square. That is, when the right square flashed on (green), the right arm of the individual was in peak flexion; when the left square flashed on (green), the left arm of the individual was in peak flexion.

Participants were required to coordinate peak flexion movements in 25 discrete 15-s trials in which the visual metronome specified one of 25 relative phase patterns (i.e., from 0° to 360° in 15° steps). The 360° trial (which is identical to the 0° trial) was used as a practice scanning trial and was presented first to the participants to familiarize themselves with the procedure. The remaining 24 patterns were randomly presented to the participant. Only the final 10 s of data collection for each scanning trial were analyzed. No feedback was provided at any time during the discrete scanning trials, to reduce the potential effects of learning.

Acquisition. All participants performed a total of 200 acquisition trials at 1 Hz over 2 consecutive days. For each day of acquisition, participants completed 10 blocks of 10 trials with a maximum 1-min rest in between blocks. The control group performed 90° for all 200 acquisition trials. The blocked group performed 100 trials of 90° one day and 100 trials of 45° the second day, with order of task presentation counterbalanced across subjects. The random group performed 100 trials of both the 90° and 45° patterns in a random schedule over the 2 days of acquisition, with the only stipulation being an equal number of each pattern presented in each block of 10 trials.

Retention/Transfer. All participants were given a retention test and two transfer tests, immediately following the end of the 2nd day of acquisition and 1 week later. The retention test consisted of a block of 10 trials of 90°, with a 1 Hz metronome and augmented visual feedback as per the acquisition trials. Transfer tests included one block of 10 trials of 90° with a 1.25 Hz metronome and visual feedback (speeded transfer) and one block of 10 trials of 270° relative phasing at 1 Hz with visual feedback (symmetrical transfer), which represents the symmetrically opposite pattern to 90°, where the right hand lags one quarter of a cycle behind the left hand. As per previous studies (e.g., Lee et al., 1995), the speeded transfer condition allowed for assessment of accuracy and stability of the learned relative phase pattern when cycling frequency is increased. The symmetrical transfer was examined because previous studies (i.e., Zanone & Kelso, 1997) have shown the development of a symmetrical attractor at 270° with practice of a 90° relative phase pattern.

Dependent Measures and Analyses. The final 10 s of data collection for acquisition, retention, transfer, and scanning trials were analyzed. This procedure allowed participants to become consistent and synchronized with the auditory

metronome at the start of the trial. Continuous measures of relative phase were calculated at a rate of 1000 Hz for all complete cycles of movement within the final 10 s of each trial. Relative phase of the left hand in relation to the right was calculated for each point after the speed and position of the limbs were rescaled to the interval $[-1, 1]$. The phase angles were calculated using the methods described by Scholz and Kelso (1989). Calculations were constrained such that all relative phase values were converted to a value ranging between the criteria $\pm 180^\circ$ (ranged relative phase). That is, if a participant attempted to perform a relative phase of 0° and actually performed at a relative phase of 359° , this value would be converted to a relative phase of -1° . Relative phase provided a description of participants' performance within and across trials.

For the set of relative phase values for each trial, a mean relative phase and standard deviation were calculated. Standard deviation represents the participant's variability within a trial, which has been shown to be an important performance variable, both at the start of practice indexing the exploration for new coordination patterns and the break from old coordination patterns and at the end of practice, indexing quality of learning. Root mean square error (RMSE) of each trial was considered a general measure of the participant's error. RMSE was calculated by first subtracting the observed relative phase from the required/criterion relative phase (constant error) for each calculated ranged relative phase. Each constant error value was squared and summed, then divided by the total number of points, and the square root of this value represented RMSE (see Franks, Wilberg, & Fishburne, 1982).

$$RMSE = \sqrt{\frac{\sum_{x=1}^n (criteria - x_n)^2}{n}}$$

This measure has been used to capture group differences in previous experiments (e.g., Hodges & Franks, 2000, 2001; Tsutsui et al., 1998) and should speak most clearly to the predictions made at the end of the introduction. Thus the standard deviation was the variation around the participant's produced relative phase value, while RMSE was the variation relative to the task goal.

The dependent measure of RMSE from the last 10 practice trials was subjected to a 3 Group (control, random, blocked) ANOVA to determine if there were any group differences prior to the start of the acquisition trials. Dependent measures from the acquisition period were subjected to either a 3 Group (control, random, blocked) $\times$ 10 Block ANOVA with repeated measures on the last factor (90° acquisition data) or 2 Group (random, blocked) $\times$ 10 Block ANOVA with repeated measures on the last factor (45° acquisition data). Dependent measures from the retention and transfer tests were subjected to a 3 Group (control, random, blocked) $\times$ 2 Time (immediate, 1 week) ANOVA with repeated measures on the last factor.

Dependent measures from the 90° scanning trials were subjected to a 3 Group (control, random, blocked) $\times$ 2 Type (scanning, learning) $\times$ 3 Time (pre-acquisition, post-acquisition, post-retention) ANOVA with repeated measures on the last two

factors. The scanning analysis was used to determine if there were significant group differences as well as significant differences between the scanning trials prior to acquisition, at the end of acquisition, and at the end of the experiment (1 week later). Analysis of type of trial (i.e., scanning versus learning trials), allowed for assessment of the validity of the scanning method by comparing performance during scanning trials and the corresponding learning trials (either acquisition or retention trials). Learning trials included in this analysis were the trials of the 90° coordination pattern that occurred the closest in time to the respective scanning trials; pre-acquisition scanning trials were compared to the final practice trial, post-acquisition trials were compared to the final acquisition trial, and post-retention trials were compared to the last retention trial of the final day of testing. If the scanning trials accurately represented the participant's coordination landscape at that moment, no difference would be expected between the scanning trials and the corresponding learning trial.

The alpha level for the entire experiment was set at .05, and the Greenhouse-Geisser Epsilon factor was used to adjust the degrees of freedom for violation of the sphericity assumption (Greenhouse & Geisser, 1959). The Tukey HSD method (Rosenberg, 1990, pp. 352-356) was used for all post-hoc comparisons.

Results

RMSE

Acquisition 90°. Results of the analysis of the last 10 practice trials showed no significant Group effect ($p = .901$), suggesting there were no significant group differences at the beginning of the acquisition period (blocked $M = 17.3$, $SE = 1.3$; random $M = 18.5$, $SE = 1.7$; control $M = 18.4$, $SE = 2.9$). The RSME group data for acquisition of the 90° coordination pattern, plotted as a function of block, is shown in Figure 2. Results of the analysis of the 90° coordination pattern showed a significant main effect for Block, $F_{4, 112}^{(1)} = 19.937$, $p < .001$. Post hoc analyses revealed a significant difference between trial block 1 ($M = 16.2$, $SE = 0.6$) and block 8 ($M = 12.5$, $SE = 0.4$). There was no significant main effect for Group ($p = .271$: blocked $M = 14.1$, $SE = 0.7$; random $M = 13.1$, $SE = 0.7$; control $M = 14.6$, $SE = 0.7$); however the Block $\times$ Group interaction effect was significant, $F_{8, 112} = 2.806$, $p = .007$. Post hoc analyses were conducted individually on each group to determine if a trial block effect was present. The blocked presentation group did not show a significant trial block effect ($F_{4, 33} = 2.224$, $p = .092$); however, there was a significant trial block effect for both the random presentation group ($F_{2, 19} = 12.212$, $p < .001$) and the single-task control group ($F_{4, 32} = 7.683$, $p < .001$). Thus the random and control groups significantly improved their performance (measured by RMSE) over the blocks of acquisition trials, while the blocked group did not. A comparison of the random and control groups, as shown in Figure 2, suggests that the random group showed greater overall improvement than the control group.

Acquisition 45°. The RSME group data for acquisition of the 45° coordination pattern, plotted as a function of trial block, is shown in Figure 3. Both groups

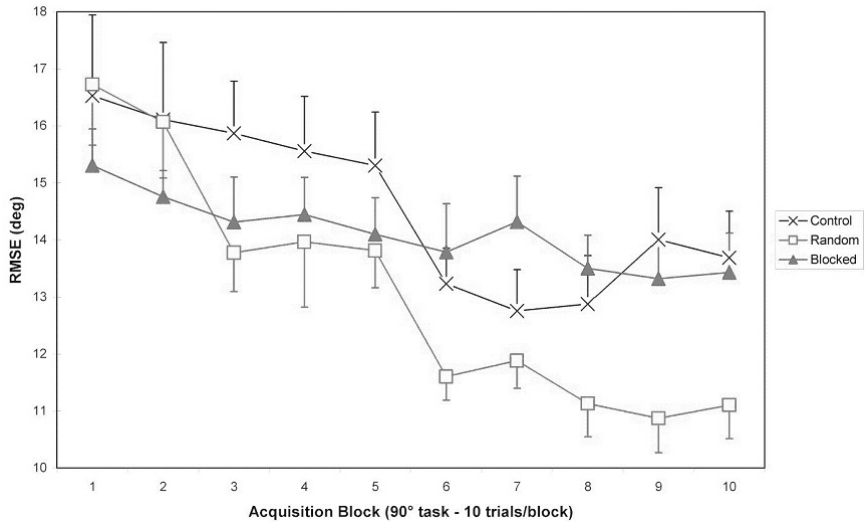


Figure 2 — RMSE performance data and standard error as a function of Block: Acquisition 90.

reduced error during acquisition of the 45° coordination pattern as evidenced by a significant main effect for Block ($F_{2,42} = 42.520, p < .001$). This was shown by a significant difference between block 1 and blocks 4 through 10 inclusive. There was no significant main effect for Group ($p = .743$: blocked $M = 18.2, SE = 1.7$; random $M = 17.4, SE = 1.7$); however the Block $\times$ Group interaction effect was significant ($F_{2,42} = 3.094, p = .049$). As with the acquisition of the 90° pattern, the block effect for the acquisition of the 45° pattern was different for the different groups. Post hoc analyses conducted individually on each group showed a significant Block effect for both groups; however, a comparison of the random and blocked groups, as shown in Figure 3, suggests that the random group showed greater overall improvement than the blocked group.

Acquisition 45°—First 18 Trials Only. Analysis of the acquisition data of both tasks (90° and 45°) showed the different groups improved at different rates, as evidenced by a Block $\times$ Group interaction effect. During acquisition of the 90° coordination pattern, the random and control groups both showed a block effect, while the blocked group did not. For the 45° coordination pattern, performance in the random group improved more than the blocked group. These findings are opposite what is normally seen in the contextual interference literature, in which the blocked group typically outperforms the random group in acquisition (i.e., Shea & Morgan, 1979; Tsutsui et al., 1998). However, previous investigations of contextual interference have involved inexperienced participants completing relatively few acquisition trials for each task. For example, Shea and Morgan (1979) used 18 acquisition trials of three barrier knockdown tasks, while Tsutsui et al. (1998) used 45 trials of three bimanual coordination tasks. Participants in the present experiment

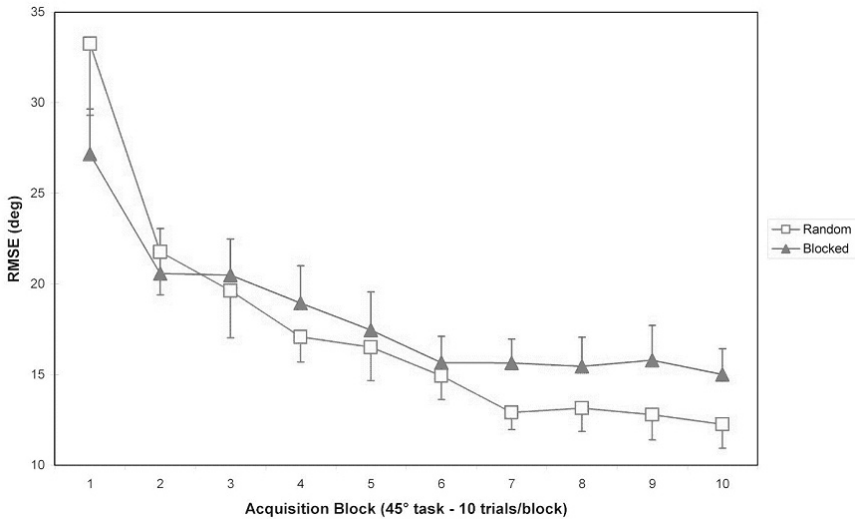


Figure 3 — RMSE performance data and standard error as a function of Block: Acquisition 45.

had completed a minimum of 30 trials before beginning the task and then undertook a further 100 trials of acquisition per task. Examination of the acquisition data from Shea and Morgan (1979) revealed that the blocked group initially outperformed the random group; however, the random group eventually reaches a similar performance level as the blocked group after only 18 trials. Examination of the first two blocks of 10 acquisition trials for both 90° and 45° tasks from this experiment (Figures 2 & 3) showed a similar and typical CI effect. However, the random group continued to improve over the next 80 trials and outperformed the blocked group during the rest of acquisition. Thus, this reversal of the typical acquisition findings for the CI effect may have simply been due to the number of acquisition trials. Providing an extended period of practice allows sufficient time for the learning benefits of the interference to be realized and expressed. Examination of the RMSE of the first 18 acquisition trials of the task that participants were not familiar with (45° coordination pattern) showed a more typical contextual interference effect. This is shown graphically in Figure 4.

Retention and Transfer

Retention performance showed a group effect that closely approached significance $F_{2,27} = 3.329, p = .051$, with no Group $\times$ Time interaction. The random group had the lowest average RMSE ($M = 10.8, SE = 0.6$), followed by the control group ($M = 11.4, SE = 0.6$) and finally the blocked group ($M = 12.9, SE = 0.6$). Neither transfer performance (speeded 90° coordination pattern and 270° coordination pattern) showed a significant Group effect or Group $\times$ Time interaction. Performance of the 270° coordination pattern did show an effect for Time, $F_{1,27} = 16.453, p < .001$,

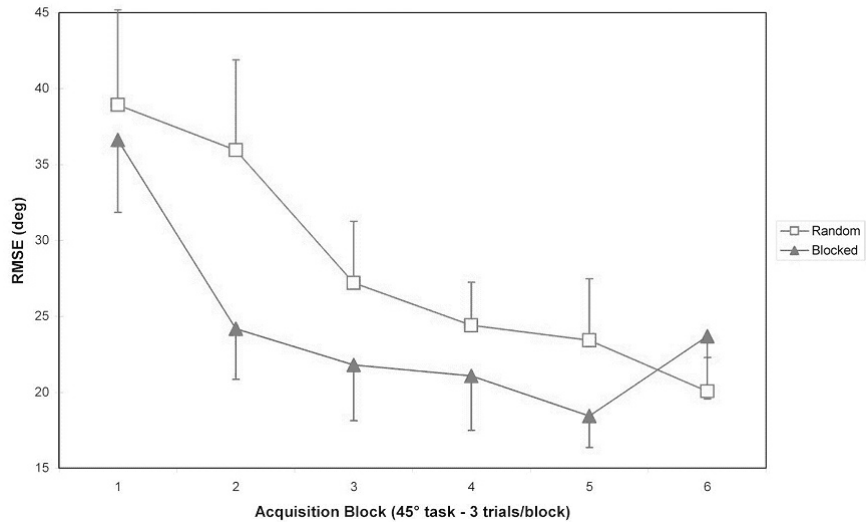


Figure 4 — RMSE performance data and standard error for first 18 trials only: Acquisition 45.

with performance significantly improving between testing immediately following acquisition ($M = 40.7$, $SE = 3.8$) and 1 week later ($M = 30.9$, $SE = 2.9$).

Scanning

Analysis of RMSE for scanning trials did show an effect for Time, $F_{2,49} = 7.204$, $p = .002$ and an effect for Type (i.e., scanning trials versus learning trials; $F_{1,26} = 135.124$, $p < .001$) but no main effect for Group or interaction effects. Post hoc analyses on the main effect for Time revealed both scanning trials ($p = .026$) and learning trials ($p < .001$) individually showed a time effect. However, post hoc analyses on type of trial showed a significant difference between scanning trials and learning trials. At all three time intervals, learning trials showed a significantly lower RMSE than scanning trials (pre-acquisition: scan $M = 67.3$, $SE = 4.8$, learning $M = 18.0$, $SE = 1.3$; post-acquisition: scan $M = 52.4$, $SE = 4.9$, learning $M = 12.0$, $SE = 0.5$; post-retention: scan $M = 56.0$, $SE = 4.5$, learning $M = 11.8$, $SE = 0.7$). Data from all three groups combined for both scanning trials and learning trials are shown in Figure 5.

Standard Deviation

Acquisition 90°. As with the dependent measure of RMSE, analysis of the standard deviation of relative phase during acquisition of the 90° coordination pattern revealed a main effect for Block $F_{5,125} = 13.892$, $p < .001$. There was no significant main effect for Group ($p = .267$: blocked $M = 13.1$, $SE = 0.6$; random $M = 12.0$, $SE = 0.6$; control $M = 13.2$, $SE = 0.6$); however, the Block $\times$ Group interaction was

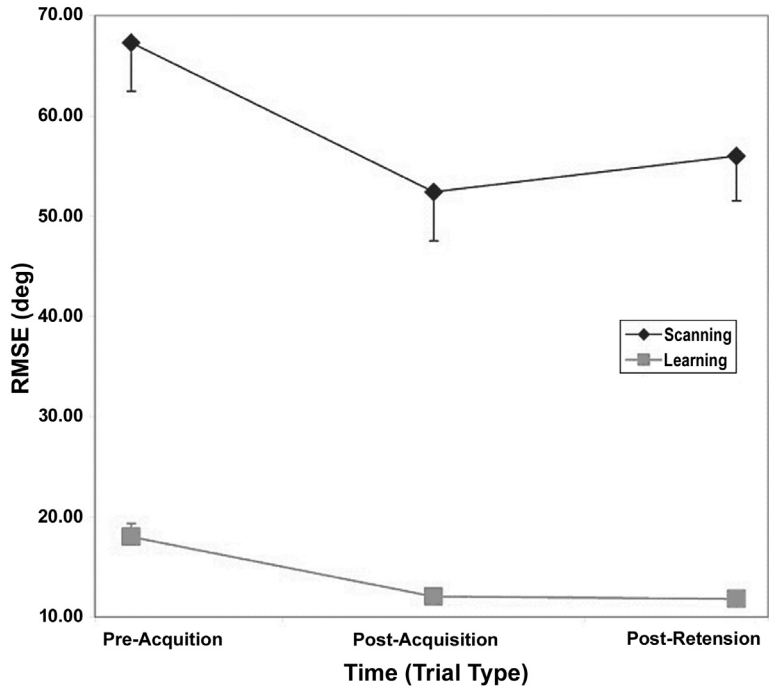


Figure 5 — RMSE and standard error of scanning performance versus learning performance: All groups combined.

significant ($F_{9, 125} = 2.477, p = .012$). Post hoc analyses were conducted on each group individually to determine if a block effect was present. As with RMSE, no block effect was found for the blocked presentation group ($F_{4, 34} = 2.002, p = .118$); however, there was a significant Block effect for both the random presentation group ($F_{2, 20} = 8.200, p = .002$) and the single-task control group ($F_{5, 45} = 6.311, p < .001$). Thus, the random and control groups significantly decreased their variability over the blocks of acquisition trials, while the blocked group did not. As with RMSE, a comparison of the random and control groups suggests that the random group showed greater overall improvement than the control group.

Acquisition 45°. Both groups were able to significantly improve their performance of the 45° coordination pattern, as evidenced by a significant main effect for Block ($F_{4, 66} = 28.499, p < .001$). There was no significant main effect for Group ($p = .617$: blocked $M = 15.1, SE = 1.1$; random $M = 14.3, SE = 1.1$); however, the Block $\times$ Group interaction effect was significant, $F_{4, 66} = 3.307, p = .018$. Post hoc analyses conducted individually on each group showed a significant block effect for both groups (blocked, $F_{3, 26} = 5.341, p = .006$; random, $F_{3, 25} = 32.915, p < .001$). As with RMSE, a comparison of the random and blocked groups suggests that the random group showed greater overall improvement than the blocked group.

Retention and Transfer. Analysis of the retention data showed no significant effect for Time ($p = .832$) or Time $\times$ Group interaction ($p = .108$); however, there was a significant Group effect ($F_{2,27} = 4.021, p = .030$). Post hoc analyses of the Group effect showed a significant difference between the blocked ($M = 12.0, SE = 0.6$) and random groups ($M = 9.8, SE = 0.6$) but no difference between the control group ($M = 10.4, SE = 0.6$) and either the blocked or random groups.

Neither transfer performance (speeded 90° coordination pattern and 270° coordination pattern) showed a significant Group effect or Group $\times$ Time interaction. However, as with RMSE, performance of the 270° coordination pattern did show an effect for Time, $F_{1,27} = 16.347, p < .001$, with performance significantly improving between testing immediately following acquisition ($M = 36.3, SE = 3.6$) and 1 week later ($M = 27.5, SE = 2.8$).

Discussion

The purpose of the present study was to determine if interference from a second task is beneficial for learning only one task. We compared performance during acquisition, retention and transfer of a single-task control group to groups performing two tasks under either high (random presentation) or low (blocked presentation) interference conditions. A secondary purpose was to determine the effects of interference and single task learning on transfer of a learned task. It was predicted that the single-task control group would outperform both the random and blocked groups during retention (consistent with the predictions of practice specificity), while both the random and blocked groups would outperform the single-task control group during transfer (consistent with predictions of the contextual interference effect). In addition, we also anticipated a typical contextual interference effect—specifically, poorer performance of the random group during acquisition but better performance during retention and transfer.

During acquisition, the groups improved performance at different rates; however, contrary to our predictions, the random group outperformed the blocked group. This difference from what is normally observed in CI literature was attributed to the high number of acquisition trials and practice trials prior to acquisition. This may have allowed sufficient time for the learning benefits of interference to be realized and expressed during acquisition rather than retention. This was supported by examination of the acquisition data from the first 18 trials of the 45° task that was not practiced prior to acquisition, as the performance on these early learning trials showed a more typical CI effect (see Figure 4).

As expected, the groups were differentiated on the basis of their retention performance (specifically in terms of variability of performance). It was expected that the single-task control group would show the best performance (lowest variability) of the three groups as a result of practice specificity. It was also expected that the random presentation group would outperform (lower variability) the blocked presentation group as a result of the contextual interference effect. Although there was a contextual interference effect in retention, with the random group outperforming the blocked group, both groups performed no different than the single-task control group. This is surprising given that the control group received

twice the number of acquisition trials when compared to either the blocked or random group.

The results of this experiment suggest that interference caused by practicing a second task is beneficial to learning, even if learning a single task. The difference in variability of performance during retention between the random and blocked groups can be attributed to the CI effect, as the increased interference of random presentation of tasks increased retention performance. This interference appeared to provide the same benefit as extra practice on the to-be-learned task as the control group performed at the same level as both the random and blocked groups, presumably due to the similarity of testing conditions in acquisition and retention. During transfer performance, there was a trend towards increased performance by both the blocked and random groups relative to the control group. Again this is consistent with the effects of CI, as groups practicing two tasks should perform better in a transfer situation, either due to comparisons between tasks (elaboration theory) or continuous reconstruction of the required movements (action-plan reconstruction) during acquisition. In addition, as both the cognitive and physical demands of the transfer task were different than those of the practice period, there would be less benefit for the single task group, as the similarity of testing conditions in acquisition and transfer would be lower than the similarities between acquisition and retention.

Results from the scanning analysis suggest that the method of scanning used in this experiment may not accurately represent the participant's ability to perform a given coordination pattern. Although both the scanning trials and learning trials showed the expected improvement from pre-acquisition to post-acquisition and post-retention, the main effect for type of trial revealed significant differences between scanning trials and learning trials. If the scan was accurately representing the performance of the participant at the given time, no difference in type of trial would be expected. The large differences in RMSE (Figure 5) between scanning trials and learning trials at all three measured times in the experiment cast serious doubt on the validity of the scanning method as an assessment of learning. This can be explained by the fact that the method used to scan participants' coordination landscape was very different from the learning trials the participants experienced. The large differences in performance suggest little transfer of learning occurred between performance of a 90° coordination pattern via Lissajous figures with concurrent, online feedback (the learning procedure) and performance of the same pattern using coincident timing of the arms with two flashing squares (the scanning procedure).

In summary, the acquisition data from this experiment did not show a typical contextual interference effect, as the random group outperformed the blocked group. However, this may be due to the experience level of the participants and the large number of acquisition trials. Retention results did show a contextual interference effect with respect to variability of performance and also showed that interference from random practice is beneficial for learning only one task. Transfer performance to a new coordination pattern showed a trend towards better performance by groups practicing two tasks versus the single task acquisition group. However, more research would be needed to draw stronger conclusions in this area.

The design of the present experiment allowed for comparison of contextual interference and practice specificity on the learning of a single task. Results from this study would suggest that extra practice on the single task is no more beneficial to learning than extra practice on a second task. These results do not support the notion of practice specificity and may suggest practice specificity is not as important as originally thought. Rather than extra trials on the single task, an equal benefit can be derived by the introduction of a second task. Results from this study also indicate, in support of previous contextual interference findings, that higher interference conditions (random practice) are more beneficial to retention performance than lower interference conditions (blocked practice). From a practical perspective, these results suggest that practitioners can benefit from requiring their performers to practice multiple tasks, in a high interference schedule, even if single-task retention is the primary concern. Thus it appears that random practice does provide benefits for learning only one task and may be used, rather than the principle of practice specificity, in many learning environments.

References

- Amazeen, P.G. (2002). Is Dynamics the Content of a Generalized Motor Program for Rhythmic Interlimb Coordination? *Journal of Motor Behavior*, **34**, 233-251.
- Battig, W.F. (1966). Facilitation and interference. In E.A. Bilodeau (Ed.), *Acquisition of Skill* (pp. 215-244). New York: Academic Press.
- Brady, F. (1998). A theoretical and empirical review of the contextual interference effect and the learning of motor skills. *Quest*, **50**, 266-293.
- Del Rey, P. (1989). Training and contextual interference effects on memory and transfer. *Research Quarterly for Exercise and Sport*, **60**, 342-347.
- Del Rey, P., Wughalter, E.H., & Whitehurst, M. (1982). The effects of contextual interference on females with varied experience in open sport skills. *Research Quarterly for Exercise and Sport*, **53**, 108-115.
- Del Rey, P., Xiaoying, L., & Simpson, K.J. (1994). Does retroactive inhibition influence contextual interference effects? *Research Quarterly for Exercise and Sport*, **65**, 120-126.
- Fontaine, R.J., Lee, T.D., & Swinnen, S.P. (1997). Learning a new bimanual coordination pattern: Reciprocal influences of intrinsic and to-be-learned patterns. *Canadian Journal of Experimental Psychology*, **51**, 1-9.
- Franks, I.M., Wilberg, R.B., & Fishburne, G.J. (1982). Consistency and error in motor performance. *Human Movement Science*, **1**, 109-123.
- Goodwin, J.E., & Meeuwse, H.J. (1996). Investigation of the contextual interference effect in the manipulation of the motor parameter of over-all force. *Perceptual and Motor Skills*, **83**, 735-743.
- Greenhouse, S.W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika*, **24**, 95-112.
- Hall, K.G., & Magill, R.A. (1995). Variability of practice and contextual interference in motor skill learning. *Journal of Motor Behavior*, **27**, 299-309.
- Henry, F.M. (1968). Specificity vs. generality in learning motor skill. In R.C. Brown & G.S. Kenyon, *Classical Studies on Physical Activity* (pp. 328-331). Englewood Cliffs, NJ: Prentice Hall.

- Hodges, N.J., & Franks, I.M. (2001). Learning a coordination skill: Interactive effects of instruction and feedback. *Research Quarterly for Exercise and Sport*, **72**, 132-142.
- Hodges, N.J., & Franks, I.M. (2000). Attention focusing instructions and coordination bias: Implications for learning a novel bimanual task. *Human Movement Science*, **19**, 843-867.
- Jarus, T., & Goverover, Y. (1999). Effects of contextual interference and age on acquisition, retention, and transfer of motor skill. *Perceptual and Motor Skills*, **88**, 437-447.
- Kelso, J.A.S. (1984). Phase transitions and critical behavior in human bimanual coordination. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology*, **15**, R1000-R1004.
- Kelso, J.A.S. (1995). *Dynamic Patterns: The Self-organization of Brain and Behavior*. Cambridge, MA: MIT Press.
- Lee, T.D. (1988). Transfer-appropriate processing: A framework for conceptualizing practice effects in motor learning. In O.G. Meijer & K. Roth (Eds.), *Complex Movement Behaviour: The Motor-Action Controversy* (pp. 201-215). North Holland: Elsevier Science.
- Lee, T.D., & Magill, R.A. (1985). Can forgetting facilitate skill acquisition? In D. Goodman, R.B. Wilberg, & I.M. Franks (Eds.), *Differing Perspectives in Motor Learning, Memory, and Control* (pp. 3-22). Amsterdam: North Holland.
- Lee, T.D., Magill, R.A., & Weeks, D.J. (1985). Influence of practice schedule on testing schema theory predictions in adults. *Journal of Motor Behavior*, **17**, 283-299.
- Lee, T.D., Swinnen, S.P., & Verschueren, S. (1995). Relative phase alterations during bimanual skill acquisition. *Journal of Motor Behavior*, **27**, 263-274.
- Magill, R.A., & Hall, K.G. (1990). A review of the contextual interference effect in motor skill acquisition. *Human Movement Science*, **9**, 241-289.
- Rosenberg, K.M. (1990). *Statistics for Behavioral Sciences*. Dubuque, IA: Wm. C. Brown.
- Schmidt, R.A. (1975). A schema theory of discrete motor skill learning. *Psychological Review*, **82**, 225-260.
- Scholz, J.P., & Kelso, J.A.S. (1989). A quantitative approach to understanding the formation and change of coordinated movement patterns. *Journal of Motor Behavior*, **21**, 122-144.
- Shea, C.H., & Kohl, R.M. (1990). Specificity and variability of practice. *Research Quarterly for Exercise and Sport*, **61**, 169-177.
- Shea, C.H., & Kohl, R.M. (1991). Composition of practice: Influence on the retention of motor skills. *Research Quarterly for Exercise and Sport*, **62**, 187-195.
- Shea, J.B., & Morgan, R.L. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology*, **5**, 179-187.
- Shea, J.B., & Zimny, S.T. (1983). Context effects in memory and learning movement information. In R.A. Magill (Ed.), *Memory and control of action* (pp. 345-366). Amsterdam: North Holland.
- Shewokis, P.A., Del Rey, P., & Simpson, K.J. (1998). A test of retroactive inhibition as an explanation of contextual interference. *Research Quarterly for Exercise and Sport*, **69**, 70-74.

- Swinnen, S.P., Lee, T.D., Verschueren, S., Serrien, J., & Bogaerds, H. (1997). Interlimb coordination: Learning and transfer under different feedback conditions. *Human Movement Science*, **16**, 749-785.
- Tsutsui, S., Lee, T.D., & Hodges, N.J. (1998). Contextual interference in learning new patterns of bimanual coordination. *Journal of Motor Behavior*, **30**, 151-157.
- Turnbull, S.D. & Dickinson, J. (1986). Maximizing variability of practice: A test of schema theory and contextual interference theory. *Journal of Human Movement Studies*, **12**, 201-213.
- Wulf, G. & Lee, T.D. (1993). Contextual interference in movements of the same class: Differential effects on program and parameter learning. *Journal of Motor Behavior*, **25**, 254-263.
- Wulf, G. & Schmidt, R.A. (1988). Variability of practice: Facilitation in retention and transfer through schema formation or context effects? *Journal of Motor Behavior*, **20**, 133-149.
- Zanone, P.G., & Kelso, J.A.S. (2002). Coordination dynamics of learning and transfer across different effector systems. *Journal of Experimental Psychology*, **28**, 776-797.
- Zanone, P.G., & Kelso, J.A.S. (1992). Evolution of behavioural attractors with learning: Nonequilibrium phase transitions. *Journal of Experimental Psychology*, **18**, 403-421.
- Zanone, P.G., & Kelso, J.A.S. (1994). The coordination dynamics of learning: Theoretical structure and experimental agenda. In S.P. Swinnen, H. Heuer, J. Massion, & P. Casaer (Eds.), *Interlimb coordination: Neural, dynamical, and cognitive constraints* (pp. 461-490). New York: Academic Press.
- Zanone, P.G., & Kelso, J.A.S. (1997). Coordination dynamics of learning and transfer: Collective and component levels. *Journal of Experimental Psychology: Human Perception and Performance*, **23**, 1454-1480.

Notes

¹Note again that degrees of freedom in all repeated measure *F* ratios have been adjusted by the Greenhouse-Geisser Epsilon Factor.

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