Dyad practice impacts self-directed practice behaviours and motor learning outcomes in a contextual interference paradigm

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Abstract

We studied dyad practice to determine whether and how alternating practice blocks with a partner impacts self-directed practice scheduling, learning, and perceptions of practice. Participants were assigned to be Partner 1 (P1) or 2 (P2). P1s had a blocked, random, or self-directed schedule, while all P2s self-directed practice of three, differently-timed keystroke-sequences. P2s showed both own error-dependent practice (switching sequences following better performance) and partner-dependent practice, with the partner's schedule impacting sequence selection and switching frequency. A partner's schedule also impacted learning. Random practice resulted in better timing accuracy than blocked practice for both partners in an immediate and delayed retention test. These data give evidence that self-directed practice behaviours and learning outcomes are modulated by a partner's practice schedule.

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The challenge of how to organize practice schedules to promote learning has captured the interest of researchers and practitioners alike for over three decades. However, these attentions have been largely devoted to learners in an isolated practice environment. Despite the ubiquity of social motor learning settings, little empirical attention has been paid to how to effectively organize multi-person practice, and the potential benefits and costs of multi-skill practice within dyad settings. This study provides a first look at the processes, outcomes, and affective perceptions associated with peer-based, multi-skill learning.

Dyadic turn-taking practice

Though the research is limited, turn-taking, dyadic practice can be an effective and efficient means of promoting learning (e.g., Granados & Wulf, 2007; Shea, Wright, Wulf, & Whitacre, 2000; Shea, Wulf, & Whitacre, 1999). This form of practice, where partners alternate between physical practice and observation, capitalizes on the inter-trial breaks that are generally required between attempts at a (complex) skill (e.g., Wulf & Shea, 2002). Rather than unfilled rest, learners can observe a co-learner. This is proposed to promote additional information processing activities which impact on subsequent practice and retention (e.g., Lee, Swinnen, & Serrien, 1994; Simon & Bjork, 2002; Wulf & Shea, 2002).

While the benefits of turn-taking have been attributed in part to the opportunity for observational learning (e.g., Granados & Wulf, 2007), this form of paired training seems to be more than simply the opportunity for both performance and observation. It is the interactive, dynamic nature of the alternating physical and observational practice that appears important to the success of paired practice. As an illustrative example, blocked physical practice on a balance task in the first half of practice, while a partner observed, before switching actor and observer roles for the second half of practice, was not as good as turn-taking practice (Shea et al., 1999). Moreover, only turn-taking practice was better than individual practice (Shea et al., 1999). Despite this finding, research on turn-taking practice to date has been limited and constrained to the learning of a single skill (e.g., stabiliometer task, Shea et al., 1999; computer-based task, Shea et al., 2000; cup-stacking, Granados & Wulf, 2007). Because of these single-skill paradigms, it has been difficult to infer when and what aspects of a partner's practice impacts one's own, such as the choice to switch skills, which is only present in a multi-skill learning context. Here we aim to study how paired practice influences the effectiveness of multi-skill motor learning, when practice organization (i.e., task-switching schedule) is experimenter-determined for one partner only and the other partner gets to choose how to practice.

Multi-skill practice organization

There is considerable evidence that certain practice schedules enhance learning more than others, particularly in terms of the "contextual interference" (CI) effect. This effect refers to the finding that while blocked practice schedules (in which all trials of a particular skill are practiced one after another before switching to a different task, reducing 'interference') are associated with better performance during practice, random schedules (in which skills are practiced unsystematically, promoting 'interference') result in better retention and transfer (for a review, see Lee, 2012).

While evidence of CI effects within observational practice is mixed (e.g., Blandin, Proteau, & Alain, 1994; Lee & White, 1990), interspersing a learner's physical practice with demonstrations (that either augment or diminish the degree of CI within the practice schedule) significantly affects both immediate motor performance and learning. For example, adding blocked ‘demonstrations’ of a keystroke-sequence timing task (i.e., a computerized run-through of the upcoming sequence, such that each key was highlighted in the order and timing it should be pressed), to a random practice schedule, reversed the typical advantages of random practice in retention (Lee, Wishart, Cunningham, & Carnahan, 1997). This random + blocked demonstration group displayed the best performance in acquisition, compared to a typical random practice only group, showing that the demonstrations were effective in reducing immediate timing error. These results were partially replicated when the interspersed computerized demonstrations matched (versus mismatched) the next trial of blocked and random practice schedules (Simon & Bjork, 2002). Mismatched demonstrations resulted in more errors in acquisition but more accurate retention than matched demonstrations. Although random groups continued to outperform blocked groups in retention, matching demonstrations impaired retention for both schedules. These findings are consistent with a cognitive effort framework of learning, which supports the implementation of practice conditions that impose greater demands on the learner’s information processing activities to promote learning (in this case, random and mismatched practice; see Guadagnoli & Lee, 2004; Lee et al., 1994).

There is accumulating evidence showing that allowing learners to make decisions regarding their practice enhances learning compared to experimenter-determined or yoked practice conditions, wherein the latter, practice is matched to another group’s schedule (for a review, see Sanli, Patterson, Bray, & Lee, 2013). Of particular relevance to the current study, giving learners control over when to switch tasks during motor skill acquisition has been shown to enhance learning compared to experimenter-imposed (including yoked) schedules, even when the amount of CI adopted is relatively low (e.g., Hodges, Edwards, Luttin, & Bowcock, 2011; Keetch & Lee, 2007). Making practice-related choices on a trial-by-trial basis enables learners to customize their practice to suit their needs (e.g., Carter, Carlsen, & Ste-Marie, 2014; Chiviacowsky & Wulf, 2005). Self-directed learners appear to make decisions to change tasks in a performance-contingent manner, switching following better (e.g., faster, more accurate) performance (e.g., Hodges, Lohse, Wilson, Lim, & Mulligan, 2014; Keetch & Lee, 2007; Wu & Magill, 2011; see also Karlinsky & Hodges, 2014 for evidence of peer-directed performance-contingent practice).

Self-directing learners have also been shown to be influenced by their previous practice experience when making task-switching decisions (Hodges et al., 2011, 2014). For example, when participants self-directed practice following blocked or random practice of key-sequence tasks, those who were initially assigned to a random practice condition later chose to switch between tasks more frequently than those who had experienced blocked practice (Hodges et al., 2014). In the current study, we evaluate whether the practice organization self-directed learners experience vicariously (via observation of a partner's schedule) modulates the task-switching strategies they choose to adopt, compared to those typically seen when practicing alone. We were interested in whether performance-contingent practice is demonstrated less, or not seen, when partners of a self-scheduled learner adopt a high or low frequency switching schedule.

Study aims

We adopted a novel dyad-practice paradigm, whereby multi-skill task-switching was either experimenter- or self-directed, to determine if and how a partner's practice schedule influences practice behaviours and learning outcomes. Three groups were tested in pairs during practice of three keypress timing tasks and individually tested for immediate and delayed retention. Partner 1s (P1s) either had a blocked, random, or self-directed schedule. All Partner 2s (P2s) self-directed their practice. Self-directed P1s did not observe their partner's practice, for control purposes. We anticipated that for these individuals, the order in which the different tasks were practiced would be performance-dependent (switching more following relatively good trials, e.g., Hodges et al., 2014; Karlinsky & Hodges, 2014; Keetch & Lee, 2007; Wu & Magill, 2011). Self-directed learners' decision-making in other conditions was expected to be impacted by the partner, with switching decisions less or no longer reflective of their own trial-to-trial performance. We also predicted that in general, exposure to a partner's random practice would promote more switching than that seen by people with blocked practice partners (Hodges et al., 2014). It was not clear whether this would benefit overall learning, due to the finding that self-directed learning outcomes do not always correlate with switching frequency (e.g., Karlinsky & Hodges, 2014).

Considering recent suggestions that self-directed and dyad practice comprise motivational benefits (e.g., Lewthwaite & Wulf, 2012), participants responded to the Intrinsic Motivation Inventory (IMI; Deci & Ryan, n.d.) to provide insight into the affective experiences associated with the different forms of practice. We hypothesized that self-directed learners would rate their practice experience more positively than participants following experimenter-determined schedules as a result of the autonomy associated with choosing how to practice.

Methods

Participants and Groups

Ninety-four right-handed females (*M* = 22.1 yr, *SD* = 3.9) volunteered to participate individually and were paid $10.50/hr. Participants had normal or corrected-to-normal vision, were naïve to the specific goals of the study, and provided informed consent. Individuals were randomly paired, and within each pair partners were randomly assigned to be Partner 1 (P1) or Partner 2 (P2). Pairs were pseudo-randomly assigned to the blocked-self (*n* = 17 pairs), random-self (*n* = 15 pairs), or self-self (*n* = 15 pairs) groups, where 'self' refers to self-directed practice. The paired group names reflect the practice (task-switching) schedule assigned to P1 followed by the practice schedule assigned to P2. Therefore, the three groups of pairs comprised six subgroups based on group and partner assignment (see Table 1 for list of groups and partner labels). Thus, the P1s in the blocked-self and random-self groups followed predetermined schedules, while all other participants self-directed their practice. The self-directed P1s could not watch or hear their partner's practice, to provide an index of self-directed practice, unmodulated by an observed partner's practice.

Task and Apparatus

The experimental task was based on Lee et al. (1997) and Simon and Bjork (2001) and involved learning to execute three different, 5-keystroke sequences on a 9-digit computer keypad (Dell SK-8115), using only the right index finger. Each sequence consisted of a unique set of keys and a distinct overall movement time (MT) goal (900, 1200, or 1500 ms). An LG computer was used to control stimulus presentation and record participants' responses via customized E-Prime 2.0 software (Psychology Software Tools, Inc., Sharpsburg, PA). Stimuli were presented on a monitor (ASUS HDMI 23 in.) set in the middle of a desk. During paired acquisition sessions, two chairs were placed side-by-side facing the monitor, with the keyboard fixed centrally on the desk. During individual testing, there was only one centrally located chair.

Procedures

The experiment was conducted over two consecutive days, with Day 1 completed in pairs and Day 2 completed alone. Day 1 began with a brief period during which the experimenter initiated some exchange with the participants (who did not know one another), before explaining the task. During task familiarization, participants were required to complete five successful trials of the same 5-keystroke sequence, which had a different pattern and goal MT to those of the experimental trials. Timing feedback was provided. Throughout the experiment, a successful trial required only that the correct keys be pressed in the correct order (regardless of MT accuracy). Participants then completed a 9-trial, random-order pretest on the three, 5-keystroke sequences used throughout the remaining phases of the experiment (3 trials/sequence). The relevant goal MT was presented before each trial and the image of the sequence remained on screen during the trial, eliminating the need for memory of the sequence. Only feedback about whether sequence execution had been “correct” or “incorrect” was provided. If the sequence was incorrectly inputted, the trial was repeated at the end of the test. While one partner completed the familiarization and pretest, the other waited outside and responded to the Edinburgh Handedness Inventory (Oldfield, 1971). The order in which partners (i.e., P1 vs. P2) performed these phases was counterbalanced.

During acquisition, partners were seated next to each other with the monitor and keyboard centered between them so that they could each easily see both at all times. They were instructed to watch one another’s practice (except for the self-directed P1s who did not observe their partner’s practice) but were asked not to communicate. They were told that the goal of the practice session was to learn to input the keystroke sequences in the goal MT, with the overall goal to do well (i.e., low error) when tested without MT feedback.

All participants were required to perform each sequence correctly exactly 24 times, such that the acquisition session consisted of 144 correct trials (72/partner). The blocked and random P1s followed experimenter-imposed practice schedules, where the blocked sequence order was counterbalanced within the group and the same sequence could not be repeated more than twice consecutively in the random schedule. All other participants decided for themselves which sequence to practice on a trial-to-trial basis. Partners practiced in a turn-taking fashion, starting with P1, and each partner completed a block of 9 trials before switching turns. We had chosen a block of 9 trials, rather than turn taking every trial in order that the P2 would be exposed to a particular schedule of practice before choosing their own schedule. The use of 9-trial blocks also maintained congruency with the other phases of the experiment (as each test comprised 9 trials) and afforded a consistent 3 trials/sequence in each random-order acquisition and test block. The self-directed control group (self-self P1s) wore earplugs, headphones playing white noise, and a blindfold during their partner's blocks. All pairs took a short break halfway through the acquisition session.

During self-directed blocks, each trial began with a "home screen," depicting the three sequences. The desired sequence was then manually selected (no time constraints). Participants were not made aware of how many trials remained for each sequence. If a sequence was chosen that had already reached criterion, the participant was prompted to choose again.

Once the sequence to be performed was identified, the goal MT was displayed for 3 s. This screen was only shown for the first three successful trials of each sequence (for each partner), but images of the sequences and goal MTs were posted above the monitor for participants to refer to in case they wanted a reminder. The sequence was then presented on screen and after 1 s a beep sounded, indicating the participant should enter the sequence whenever ready. An "S" marked the start key of the sequence, with the order in which to press the remaining keys identified by black adjoining lines. After five keys had been pressed, the sequence remained on screen for a further 3 s before feedback was displayed. This delay was expected to provide ample time for learners to engage in information processing activities surrounding error detection and estimation before receiving MT feedback, and hence not show feedback dependence when tested without knowledge of results (KR).

The feedback screen informed participants, (a) whether the keys were pressed in the "correct" or "incorrect" order, (b) total MT in ms (assessed from the start of the first keystroke to the fifth keystroke), and (c) signed MT error (constant error, CE) in ms. This information was shown for 4 s. After an inter-trial interval of 3 s, either the home screen or the next goal MT/sequence appeared. If a trial was “incorrect,” the trial was recycled and was either, (a) repeated at the end of the relevant sequence’s set of trials (blocked schedule), (b) repeated at the end of the acquisition trials (random schedule), or (c) available to be chosen again (self-directed schedule).

To encourage participants to attend to their partner’s practice, MT feedback was temporarily withheld (without warning) on trial 12, 30, and 51 for each partner. On these trials, both partners (except the self-directed P1 controls during their partner’s turns) were prompted to independently record an estimation of either the just performed total MT or MT constant error.[1]

At the end of acquisition, participants responded to the interest/enjoyment, perceived competence, perceived choice, and effort subscales of the IMI (Deci & Ryan, n.d.). The wording of the IMI items was customized to the task. Participants additionally responded to adapted versions of the perceived competence and perceived choice subscales, probing their perceptions of their partner’s competence and choice over their practice. A 9-trial posttest, identical to the pretest (i.e., random schedule, no MT feedback) was then completed individually, while the partner waited outside (same counterbalanced order as for the pretest).

Participants returned alone the next day to complete four different, 9-trial delayed retention tests (each 3 trials/sequence), which varied in terms of the order in which the sequences were presented during the test (random vs. blocked sequence order) and whether or not MT-related KR was provided during the test. During the first two tests, participants did not receive KR, whereas they received KR during the last two tests. All participant groups completed all four delayed retention tests in the following order: i) random-order/no-KR, ii) blocked-order/no-KR, iii) random-order/KR, iv) blocked-order/KR. During random-order tests, the goal MT was displayed on every trial, while during blocked-order tests, the goal MT was displayed on the first trial of each sequence's set of trials. Images of the sequences and goal MTs remained posted above the monitor if reminders were needed. At the end of testing, all participants responded to a customized questionnaire probing their perceptions of their practice experience and practice-scheduling decisions where appropriate (based on Wu & Magill, 2011). Responses to each question were based on a 7-point Likert-type scale, where 1 = not at all true and 7 = very true. Participants were then fully debriefed and compensated for their time.

Measures and Analysis

Self-directed switching behaviours. We evaluated three features of self-directed task-switching including switching strategy, switching frequency, and proportion matching. If task-switching was performance-contingent, absolute errors (AE) should be lower on "switch" trials than on the preceding trial ("switch - 1"). These AE data were analyzed in a 4 Subgroup (self-directed only) x 2 Trial-type (switch or switch - 1) mixed ANOVA, with repeated measures (RM). Switching frequency was also assessed and compared across the 4 self-directed subgroups in a univariate ANOVA. A Pearson's *r* correlation was run to assess similarities in frequency of switching across the self-self pairs. One final way we measured the influence of a partner on self-directed practice was in terms of the proportion of sequences that were matched/block (i.e., P2s matched the P1s' sequences from the preceding block). The mean proportion of matched sequences was analyzed in a 3 Subgroup (P2s only) univariate ANOVA. Pearson's *r* correlations were used to assess relationships between these switching frequency and proportion of matched trials measures and retention test outcomes.

Percentage error. Absolute error (AE) in MT was calculated for each trial and converted to percent MT error (%MTE) based on the trial's associated MT goal, to normalize the size of the error to the goal of the sequence and enable comparisons across the three sequences within the same analysis block (Hodges et al., 2014; Karlinsky & Hodges, 2014; Simon & Bjork, 2001, 2002). Specifically, for each trial, we divided the AE in MT by the relevant MT goal, and multiplied the result by 100%. For example, for an AE of 100 ms, the %MTE for each of three sequences would be 11.1% (100/900 x 100), 8.3% (100/1200 x 100) and 6.7% MTE (100/1500 x 100). Variable error was also analyzed but the results mirrored those of %MTE and were thus omitted for brevity.

We separately analyzed the blocked-self vs. random-self groups to capture any potential differences between experimenter- vs. self-directed practice and the self-self P1s vs. P2s, to assess the influence of partner observation. Error data for the pretest, acquisition, posttest, and delayed retention tests were analyzed in (sub)Group x Partner x Block RM ANOVAs.

Questionnaires. Participants' average score for each multi-item subscale of the IMI (interest/enjoyment, perceived choice, perceived competence, effort), and the adapted partner-related choice and competence scales was calculated and submitted to separate Group x Partner ANOVAs. Similar analyses were used for the post-practice experience measures.

Greenhouse-Geisser corrections were applied to the degrees of freedom for violations to sphericity. Significant effects and interactions were followed up with Tukey HSD procedures (all *p*s < .05 reported). Cohen's **f** values are reported as measures of effect size (where $\mathbf{f}^2$ x 100 gives an indication of % variance accounted for), such that .25 - .5 is considered a medium to large effect, and power values ($1 - \beta$) are given for non-statistically significant effects where $F > 1$. Any correlations > .30, considered a medium effect size (Cohen, 1992), are reported, along with the associated *p* value.

Results

Incorrect trials (i.e., wrong key pressed or key pressed before the beep) constituted 1.9% of all trials and were eliminated from analysis. Trials on which the MT error was greater than 1000 ms were considered errors and removed from further analysis (~0.05% of all correct trials). One participant (blocked-self P1) was excluded from analyses as she did not return for Day 2. Based on high errors in the no-KR retention test (>2.5 SDs of group's mean), four participants, across four different subgroups, were excluded from statistical analysis (1 blocked-self P1, 1 random-self P1, 1 self-self P1, and 1 blocked-self P2). In all cases, the data of the excluded participant's partner were maintained. The excluded P1s' practice schedule data were also still used in analyses related to their partner's self-directed switching behaviours (i.e., proportion match analysis and self-self switching frequency correlation). The final *n*s (in brackets) for the six partner subgroups within the three groups of pairs were as follows; blocked (15) – self (16); random (14) – self (15); and self (14) – self (15).

Performance-dependent and partner-dependent behaviours

In general, self-directed learners organized practice in a performance-contingent fashion based on findings that errors (i.e., AE) were significantly lower on switch trials (M = 93.7 ms, SD = 38.4 ms) than on the preceding trial (switch - 1; M = 113.0 ms, SD = 37.3 ms), irrespective of subgroup. This was confirmed by a significant and large effect of trial-type, $F(1, 56) = 26.85$, $p < .001$, $\mathbf{f}$ = .96, but no effect of subgroup ($F < 1$), nor a Subgroup x Trial-type interaction, $F(3, 56) = 1.20$, $p = .32$, $1 - \beta = .31$.

Switching frequency was shown to be dependent on subgroup, as illustrated in Figure 1 and evidenced by a main effect when comparing across the four self-directed subgroups, $F(3, 56) = 3.57$, $p = .02$, $\mathbf{f} = .44$. Post-hoc analysis showed that practice with a random partner led to more frequent task-switching (random-self P2s; ~36 trials) than practice with a blocked partner (blocked-self P2s; ~21 trials). There was a tendency for the random-self P2s to switch more than

P2s watching self-directed practice (self-self P2s; ~22 trials), p = .052. There were no other significant differences (self-self P1s; ~29 trials).

We also correlated switching frequency among the self-directed pairs who could choose what to practice. As can be seen in Figure 2, there was not a significant relation across the pairs ($r(15) = .12$, $p = .68$), but there appeared to be two relationships dependent on whether the P1s adopted a low (black symbols) or high (grey symbols) switching frequency. This was confirmed when we performed a median split analysis based on P1 ‘low-switchers’ (M = 8.57 switches, SD = 6.32) and ‘high-switchers’ (M = 31.63 switches, SD = 13.11). For the low-switchers, P2s matched the switching frequency of their partners, $r(7) = 0.93$, $p = .003$, but this was not the case for the P1s who switched frequently, where a trend towards a negative relation was shown, $r(8) = -0.32$, $p = .44$ (i.e., more switching by P1s, less switching by P2s).

A final analysis designed to give an indication of sequence matching among the self-directed P2s showed evidence that learners paired with blocked-schedule partners matched the content of their partner’s preceding practice block (blocked-self P2s; M = 41%, SD = 16%) significantly less than those paired with random-schedule partners (random-self P2s; M = 81%, SD = 6%) and self-directed partners (self-self P2s; M = 72%, SD = 18%). This was confirmed by a large, main effect of subgroup, $F(2, 43) = 32.93$, $p < .001$, $\mathbf{f} = 1.24$ and post-hoc Tukeys comparing the blocked-self P2s to the other P2 subgroups (ps < .001).

Outcome effects in acquisition and retention

Random and blocked groups. The blocked-self and random-self groups’ mean %MTE across all testing phases is presented in Figure 3A. There were no group- or partner-related differences in the pretest (Fs < 1). Participants improved across practice, $F(5.03, 281.76) = 3.90$, $p = .002$, $\mathbf{f} = .27$, confirmed by a linear trend component to the block effect ($p = .005$). Surprisingly, performance in acquisition did not vary as a function of group or partner (*F*s < 1), nor were there any significant Group x Partner interactions (3-way: $F(5.03, 281.76) = 1.58$, $p = .17$, $1 - \beta = .55$).

In immediate retention (posttest), there was a typical, medium sized CI effect, whereby the random-self group had significantly less error (*M* = 9.48%, *SD* = 2.75%) than the blocked-self group (*M* = 11.44%, *SD* = 4.15%), $F(1, 56) = 4.70$, $p = .034$, **f** = .29. There were no partner-related differences. On Day 2, out of the four delayed retention tests, only the blocked-order/KR retention test yielded any group differences, whereby the random-self group (*M* = 7.19%, *SD* = 2.69%) had lower error than the blocked-self group (*M* = 9.55%, *SD* = 5.22%), $F(1, 56) = 4.76$, $p = .03$, **f** = .29. Again, there were no partner-related effects (*F*s < 1).

Self-directed group. Mean %MTE for both partners in the self-self group is presented in Figure 3B. There were no partner differences in the pretest ($F < 1$). Both partners improved across practice, evidenced by a main effect of block, $F(7, 189) = 7.19$, $p < .001$, **f** = .60, which had a significant linear trend component ($p < .001$). There were no partner-related effects (*F*s < 1). Although there was a trend for the P1 (no-observe) partners to have less error in in the posttest, this was not significant, $F(1, 27) = 2.33$, $p = .15$, $1 - \beta = .30$. The delayed retention tests did not yield any partner-related differences (*F*s < 1).

Relations between behaviours and outcomes

Across the self-directed subgroups, frequency of task-switching was negatively related with %MTE during the immediate posttest, although this was only statistically significant for the random-self P2s ($r(15) = -.64$, $p = .01$). More frequent switching was generally related to lower error (blocked-self P2s, $r(16) = -.48$, $p = .06$; self-self P2s, $r(15) = -.43$, $p = .11$). The self-directed, P1 controls did not show any relation between switching frequency and %MTE (self-self P1s, $r(14) = -.01$, $p = .99$). Relationships between task-switching and %MTE did not persist in the delayed retention tests, with the exception of random-self P2s in the blocked-order/KR test, $r(15) = -.57$, $p = .03$ and a trend for the self-self P2s in the random-order/no-KR test, $r(15) = -.33$, $p = .23$ (all other *r*s < .30).

We were also interested in whether sequence matching moderated retention error, as shown in previous research involving interspersed demonstrations of matched or mismatched sequences (Lee et al., 1997; Simon & Bjork, 2002). For the blocked-self group, matching a partner's practice was related to higher error (%MTE) for both members of the pair in the immediate posttest; blocked-self P1s, $r(15) = .53$, $p = .04$; blocked-self P2s, $r(16) = .57$, $p = .02$. In contrast, there were negative correlations between matching and %MTE in the posttest within the random-self pairs, although these were not significant; random-self P1s, $r(14) = -.35$, $p = .21$; random-self P2s, $r(15) = -.42$, $p = .12$. These relationships were not observed for the self-directed P2s in delayed retention (all *r*s < .30). However, similar relationships between matching and error tended to persist for the P1s across the delayed retention tests, such that being matched was related to higher error for blocked-self P1s (blocked-order/no-KR test: $r(15) = .35$, $p = .20$; blocked-order/KR test: $r(15) = .39$, $p = .16$), but lower error for random-schedule P1s (random-order/no-KR test: $r(14) = -.34$, $p = .23$; blocked-order/no-KR test: $r(14) = -.53$, $p = .049$; random-order/KR test: $r(14) = -.54$, $p = .048$; all other *r*s < .30).

Measures of affective experiences related to motivation

Intrinsic Motivation Inventory. The data were analyzed separately for the self-self group and the CI-paired groups (random-self; blocked-self), but the data for all groups are presented in Table 2. Observing a partner (or not) did not impact the self-directed practice experiences for the self-self pairs. They generally scored medium to high on all measures and there were no partner-related effects (interest/enjoyment: $F(1, 27) = 1.34$, $p = .26$, $1 - \beta = .20$; effort: $F(1, 27) = 2.07$, $p = .16$, $1 - \beta = .28$; all other scales, Fs < 1).

For the CI-paired groups, the blocked-self P1s had higher perceived self-competence than the random-self P1s, but this was not the case for the partners who self-directed practice. Rather the random-self P2s had higher self-competence ratings than the blocked-self P2s. This was evidenced by a significant Group x Partner interaction, $F(1, 56) = 7.95$, $p = .007$, $\mathbf{f} = .38$. Perceptions of partners' competency were generally high and consistent across the four CI-paired subgroups (i.e., no group- or partner-related effects, Fs < 1).

Not surprisingly, the self-directed P2s perceived greater choice over their own practice than P1s, as evidenced by a partner-effect, $F(1, 56) = 5.75$, $p = .02$, $\mathbf{f} = .32$. There were no group-related effects. Congruently, the P1s perceived their self-directing partner as having greater choice over their practice, $F(1, 56) = 10.01$, $p = .003$, $\mathbf{f} = .42$. Again, there were no group-related effects (Fs < 1). There were no group- or partner-related effects with respect to interest/enjoyment towards practicing the tasks or perceptions of effort (Fs ranged from < 1-1.74).

Paired practice experience questionnaire. The questionnaire's items and results are presented in Table 3. While ratings were generally high, observing a partner's practice was perceived as more helpful by self-directed learners than by their partners (in the CI-paired groups), $F(1, 56) = 4.96$, $p = .03$, $\mathbf{f} = .29$. Moreover, the blocked-self and random-self P1s rated watching their partner as more interfering for their own performance than their self-directed P2 counterparts, $F(1, 56) = 5.87$, $p = .019$, $\mathbf{f} = .32$. For both these items there were no group differences.

With respect to competition and the desire to be more accurate than their partner, there were no group or partner differences. When asked whether they would have preferred to practice alone, participants' ratings were generally low, but the blocked-self group cited a greater preference (*M* = 3.96, *SD* = 2.13) than random-self group (*M* = 2.79, *SD* = 1.61), $F(1, 56) = 5.82$, $p = .02$, **f** = .31 (Group x Partner: $F(1, 56) = 2.22$, $p = .14$, $1 - \beta = .31$).

Self-directed practice questionnaire. When the P2s were asked whether their practice decisions were influenced by their partner's schedule, the random-self P2s (*M* = 1.60, *SD* = .83) perceived this to be less true (*p*s < .05) than the blocked-self P2s (*M* = 3.69, *SD* = 2.06) and self-self P2s (*M* = 3.80, *SD* = 2.51), $F(2, 43) = 6.19$, $p = .004$, **f** = .54. Consistent with the task-switching strategy observed in the behavioural data (i.e., lower error on switch than pre-switch trials), self-directed learners near unanimously reported repeating the same sequence following relatively poor performance (87%) and the majority reported choosing to practice a different sequence following relatively good performance (57%; see Table 4). However, this latter finding was primarily driven by the random-self P2 and self-self P1 subgroups (66%). If given the opportunity to redo the practice session, most reported they would not change anything (53%) or that they would switch sequences less often (37%). Overall, the questionnaire results demonstrate learners' desire to repeat poorly performed sequences and their opinion that less switching would be better for learning (see also e.g., Hodges et al., 2014; Karlinsky & Hodges, 2014; Simon & Bjork, 2001; Wu & Magill, 2011).

Discussion

We assessed if and how vicarious practice experiences related to a partner's practice schedule impacted self-directed task-switching and motor learning. In doing so, we applied a novel dyad-learning paradigm, which also provides insights into practice scheduling behaviours (and perceptions) within social contexts. Self-directed practice was similar across groups in its performance-contingent nature, but it was modulated by a partner's schedule with respect to the frequency of task-switching and matching vs. mismatching of practice content.

In terms of practice choices, a partner's random practice promoted task-switching, leading self-directed learners to incorporate greater CI into their practice. Our paradigm also afforded consideration of an as yet unexamined aspect of self-directed multi-skill practice scheduling, that is, how learners choose to match or mismatch observed behaviours. The random-self P2s who were paired with a random-schedule partner seemed to compensate for the high switching they observed by matching the content of their partner's practice across blocks, potentially to achieve a more reasonable or "optimal" level of challenge (see Guadagnoli & Lee, 2004). For this random-self P2 subgroup, more matching was related to lower error in the posttest. In contrast, when observing a blocked partner, self-directed learners (blocked-self P2s) showed less matching of content (p = .06). This seemed to have modulated outcome-related effects, as less matching for this group (that was already observing an "easy" schedule of practice) was associated with lower error in the posttest (see also Lee et al., 1997; Simon & Bjork, 2002). That self-directed learners could select for themselves when to emulate may have contributed to these subgroups perceiving a partner's practice as more helpful and less interfering than the predetermined-schedule subgroups. These findings are consistent with a cognitive effort framework of learning, which supports the implementation of practice conditions that impose demands on the learner's information processing activities to promote learning (without exceeding a skill level-appropriate load; Guadagnoli & Lee, 2004). Importantly, despite the impact of a partner on aspects of practice scheduling, self-directed learners did not sacrifice the performance-contingent nature of their task-switching.

We predicted that a self-directed group that did not view another's practice (i.e., self-self P1s) would adopt an error-dependent scheduling strategy, choosing to switch tasks following relatively good performance (e.g., Hodges et al., 2014; Karlinsky & Hodges, 2014; Wu & Magill, 2011), which was confirmed. For the other self-directed groups that watched a partner, we also saw a similar error-dependent strategy, where timing errors were, on average, lower on switch trials than on the preceding trial (and the no-observation, control P1s were not different in the relative differences in error across switch and pre-switch trials). Therefore, this type of (own) performance-contingent practice withstands external influences presented by social learning settings, even though behaviours appear to be moderated by a partner. It is likely that a relative increase in the amount of switching for learners observing a random-schedule partner is still moderated by the individual's own performance error.

One of the potential issues with the current design was that practice was alternated across blocks rather than trial-to-trial. This was done so that matched pairs would be privy to the practice schedule of their partner immediately (i.e., blocked or random). However, alternating practice on a trial-to-trial basis would allow consideration of whether self-directing learners prefer demonstrations to serve a modeling and/or feedback function (where demonstrations would match the learner's to-be performed or just performed skill, respectively), as well as whether decisions to match or mismatch are related to the success of the partner (i.e., error).

In terms of overall error, the random-self group showed less error on the immediate, no-KR posttest, as well as in the blocked-order/KR retention test, compared to the blocked-self group (although they did not differ on the other tests of retention). These posttest differences were achieved without the typically seen degradation of performance in acquisition as a function of random practice. We infer that self-directed learners showed a small benefit from observing random-schedule practice, in line with previous research showing that interspersed demonstrations that augment the CI within practice is beneficial for learning (Simon & Bjork, 2002). The lack of partner-related effects or interactions in these group-level outcomes provides evidence that self-directed learning does not depend on achieving the high levels of CI obtained via random practice (e.g., Keetch & Lee, 2007; see also Karlinsky & Hodges, 2014). However, observing random practice promoted task-switching, and for this subgroup (random-self P2s), greater switching was associated with lower error in post-testing and the blocked-order/KR delayed retention test. Whether these task-switching levels uniquely related to these learning effects, or whether there were additive benefits of task-switching and observed random practice remains to be disentangled. There is evidence that pure observational practice of a random (vs. blocked) practice schedule is sufficient to bring about CI-related effects in retention (Blandin et al., 1994; Wright, Li, & Coady, 1997; yet see Lee & White, 1990).

Because we were interested in how partners influence each other in a learning paradigm, we also asked questions to probe the perceptions and strategies guiding their performance. Contrary to predictions of some authors, self-directed practice was not associated with higher perceptions of interest/enjoyment compared to predetermined conditions (*cf*. Lewthwaite & Wulf, 2012; Sanli et al., 2013), even though autonomy (choice) perceptions were higher in the self-directed subgroups. This is consistent with recent findings that self-controlled practice enhanced learning over yoked practice in the absence of augmented motivation (Ste-Marie, Vertes, Law, & Rymal, 2013). However, it is possible that the current dyad context promoted interest/enjoyment among the predetermined-schedule learners, due to enhanced 'relatedness' (e.g., Lewthwaite & Wulf, 2012).

While all groups perceived their competency as fairly high, the relatively high perceptions of competence associated with blocked rather than random practice, are commensurate with other CI-related work (Simon & Bjork, 2001, 2002). The ease of practice is often seen as an indication of overall learning, despite outcome data showing this not to be the case. Also worth noting, is that all groups rated their partner's competency as high, which should have given good reason for copying (switching or matching).

Dyad practice provides the opportunity for social comparisons. Researchers have demonstrated that relative (comparative) feedback about another (either a peer or average) influences one's competency beliefs and potentially motor skill learning (e.g., Wulf, Chiviacowsky, & Lewthwaite, 2010). Comparative effects have usually been based on virtual or experimenter-provided comparisons, but a real partner is potentially a better model for assessing comparative information, as we typically judge ourselves in reference to how people in our immediate environment are doing (Stanne, Johnson, & Johnson, 1999). Indeed, all our groups reported some desire to be more accurate than their partner, despite the fact that they were not being evaluated in reference to each other.

The data from this investigation, though informative as to when and what types of influence a partner can have on another's practice, also yielded some unexpected effects, or lack of effects, with respect to behavioural outcomes. The first is the lack of difference between the self-directed partners that did or did not observe their partner. Although we had evidence with the blocked-self and random-self groups that observation affected practice and outcomes, here this was not the case. This may be related to the large variability between individuals as to how they practiced and difficulties in observing matched behaviours when only a few showed very blocked or high random schedules. Indeed, we saw stronger relationships between partners' switching frequencies when we separately assessed the relatively low-switching P1s (and partners) from the relatively high-switching P1s (and partners). Whether self-directing partners would be more or less likely to adopt similar task-switching habits when both members of the pair can observe one another remains to be tested. Further insight into how learners choose to practice and potential task-sharing between pairs could also be gained by removing the constraint that all sequences be practiced equally.

Another issue concerns CI-related effects. Although the random-self group showed less error than blocked-self group in the posttest and blocked-order/KR delayed retention test, we did not see group differences in practice or in the no-KR delayed retention tests. As the CI effect is relatively robust in such simple tasks as these (and has been shown previously using these same keystroke sequences and goal MTs; Hodges et al., 2014; Simon & Bjork, 2001, 2002), it is possible that the addition of a partner's 'demonstrations' modulated the strength of the typical CI effect. However, there were other factors that differed from a typical task design including rest between blocks during a partner's turns, trials without feedback in practice, and pretesting. All of these factors could potentially dilute group differences due to CI, as these first two factors would serve to reduce the ease of blocked practice compared to random, whereas the latter might decrease the negative impact of random practice. Indeed, we made these changes to facilitate performance in the no-KR retention tests due to findings from a previous study where practice with feedback did not transfer well to conditions without (Karlinsky & Hodges, 2014).

In summary, we have provided evidence showing that when people learn in pairs their practice behaviours are influenced by their partners, but not in such a way that it impacts the strategies they typically adopt when performing alone. In this task, as with others, this was evidenced by performance-contingent practice, involving increased switching on lower vs. higher error trials. In addition, self-directed learners showed some susceptibility to the practice behaviours of a co-learner, especially when the latter exhibited particularly salient blocked or random practice schedules. We anticipate that such investigations of learning in a social context will be important for guiding or affirming learning principles that have been based on an individual context. Given potential efficiencies from such shared practice contexts as well as their commonality in many motor learning settings, this will be an important line of inquiry to pursue towards enhancing not only theoretical discourse, but also applied motor learning.

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Footnote

1: Analysis of the estimation data (i.e., actual error - estimated error) did not yield any group, partner (P1, P2) or estimation-type effects (Own, Partner). Participants were just as good at estimating their own error as they were for their partner. We did not expect this to depend on group.

Table 1: *A summary of the three pair groups and their subgroup labels for each partner (Partner 1 and 2)*

Group name	*n* (pairs)	Partner 1 (P1)		Partner 2 (P2)	
		Order	Label	Order	Label
Blocked-Self	17	Blocked	Blocked-Self P1	Self	Blocked-Self P2
Random-Self	15	Random	Random-Self P1	Self	Random-Self P2
Self-Self	15	Self[1]	Self-Self P1	Self	Self-Self P2

Note. 'Order' refers to the practice (task-switching) schedule followed during the acquisition session. 'Self' means that practice was self-directed.

[1] The self-self P1s did not observe their partner's practice for control purposes.

Table 2: *Mean ratings (and SDs) for the Intrinsic Motivation Inventory subscales and customized partner-related subscales*

Measure	Blocked-Self		Random-Self		Self-Self	
	P1	P2	P1	P2	P1	P2
Interest/enjoyment	3.9 (1.4)	3.9 (1.3)	3.9 (1.9)	4.0 (1.4)	4.7 (1.4)	4.1 (1.4)
Competence						
Own	4.9 (0.8)	4.0 (1.0)	4.0 (0.9)	4.7 (1.1)	4.6 (0.9)	4.3 (1.2)
Partner	4.9 (0.9)	4.8 (0.9)	5.0 (1.0)	5.0 (0.8)	N/A	5.1 (1.0)
Choice						
Own	4.8 (0.8)	5.3 (0.7)	4.5 (1.0)	5.1 (0.8)	5.3 (0.9)	5.4 (0.9)
Partner	5.0 (0.5)	4.5 (1.1)	5.0 (0.8)	4.2 (1.0)	5.1 (1.0)	5.0 (0.9)
Effort	5.2 (0.8)	5.2 (1.2)	5.0 (1.4)	5.7 (1.0)	5.3 (1.1)	5.8 (0.9)

Note. The self-self P1s did not provide ratings regarding their perceptions of their partner's competence at the keystroke sequence task, as they did not observe their partner's practice. Note that P1s for the other groups did not have choice over their practice schedule. Scales ranged from 1-7.

Table 3: *Mean ratings (and SDs) to customized paired practice experience questionnaire*

	Blocked-Self		Random-Self		Self-Self	
	P1	P2	P1	P2	P1	P2
1. Watching my partner helped my own performance	4.5 (1.3)	5.6 (1.0)	5.1 (1.4)	5.5 (1.3)	3.6 (1.3)[1]	4.5 (1.6)
2. Watching my partner interfered with my own performance	2.7 (1.4)	2.3 (1.3)	3.4 (1.6)	2.1 (1.2)	2.9 (1.2)[2]	2.9 (1.5)
3. I wanted to be more accurate than my partner	5.0 (1.6)	4.4 (1.3)	5.3 (1.9)	4.9 (1.9)	4.8 (1.5)	4.7 (1.4)
4. I would have preferred to practice alone	4.6 (2.1)	3.3 (2.0)	2.7 (1.8)	2.9 (1.5)	3.7 (1.5)	3.4 (2.0)

Note. All questions were responded to using a 7-point Likert-type scale, where 1 = not at all true and 7 = very true.

[1] As the self-self P1s did not observe their partner, they responded to the question, “Being watched by my partner helped my own performance.”

[2] As the self-self P1s did not observe their partner, they responded to the question, “Being watched by my partner interfered with my own performance.”

Table 4: *Frequency of responses to questions assessing self-directed practice choices*

	Blocked-Self	Random-Self	Self-Self	
	P2	P2	P1	P2
1. If I did well on a trial practicing a certain pattern, I would choose...				
A) The same pattern again	7	3	3	5
B) A different pattern	8	10	9	7
C) Random	0	1	0	1
D) Other	1	1	2	2
2. If I did poorly on a trial practicing a certain pattern, I would choose...				
A) The same pattern again	13	14	11	14
B) A different pattern	2	0	1	0
C) Random	0	0	0	0
D) Other	1	1	2	1
3. If I could redo the practice session, I would...				
A) Switch patterns more often	0	2	2	1
B) Switch patterns less often	6	6	4	6
C) Not change anything	10	6	8	8
D) Other	0	1	0	0

Figure Captions

Figure 1. Mean number of trials (and SD bars) where participants switched to a different sequence over the course of the 72-trial acquisition session. Black bars = experimenter-determined task-switching. Grey bars = self-directed task-switching.

Figure 2. Scatter plot showing the self-self partners' switching frequency and linear trend lines.

Figure 3A&B. Percentage movement time error (%MTE) as a function of experimenter- or self-directed practice within A) the blocked-self and random-self pairs or within B) the self-self pairs that either did not observe (P1) or did observe (P2) their partner's practice. All blocks consisted of 9 trials. KR = knowledge of MT results, R = random sequence order, B = blocked sequence order.

Fig 1

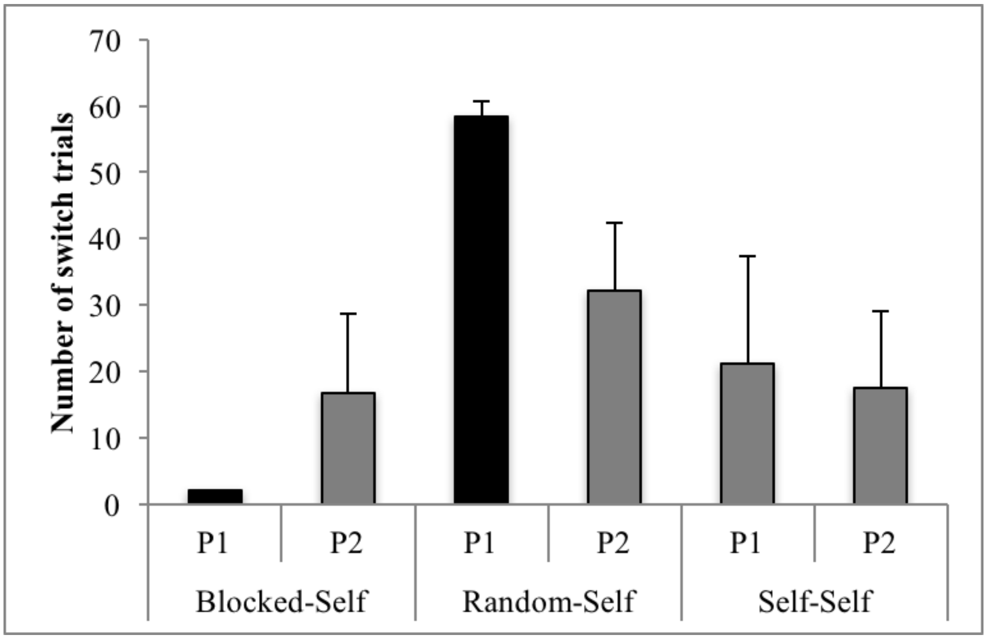

70
60
50
40
30
20
10
0
Number of switch trials
P1
P2
P1
P2
P1
P2
Blocked-Self
Random-Self
Self-Self

Fig 2

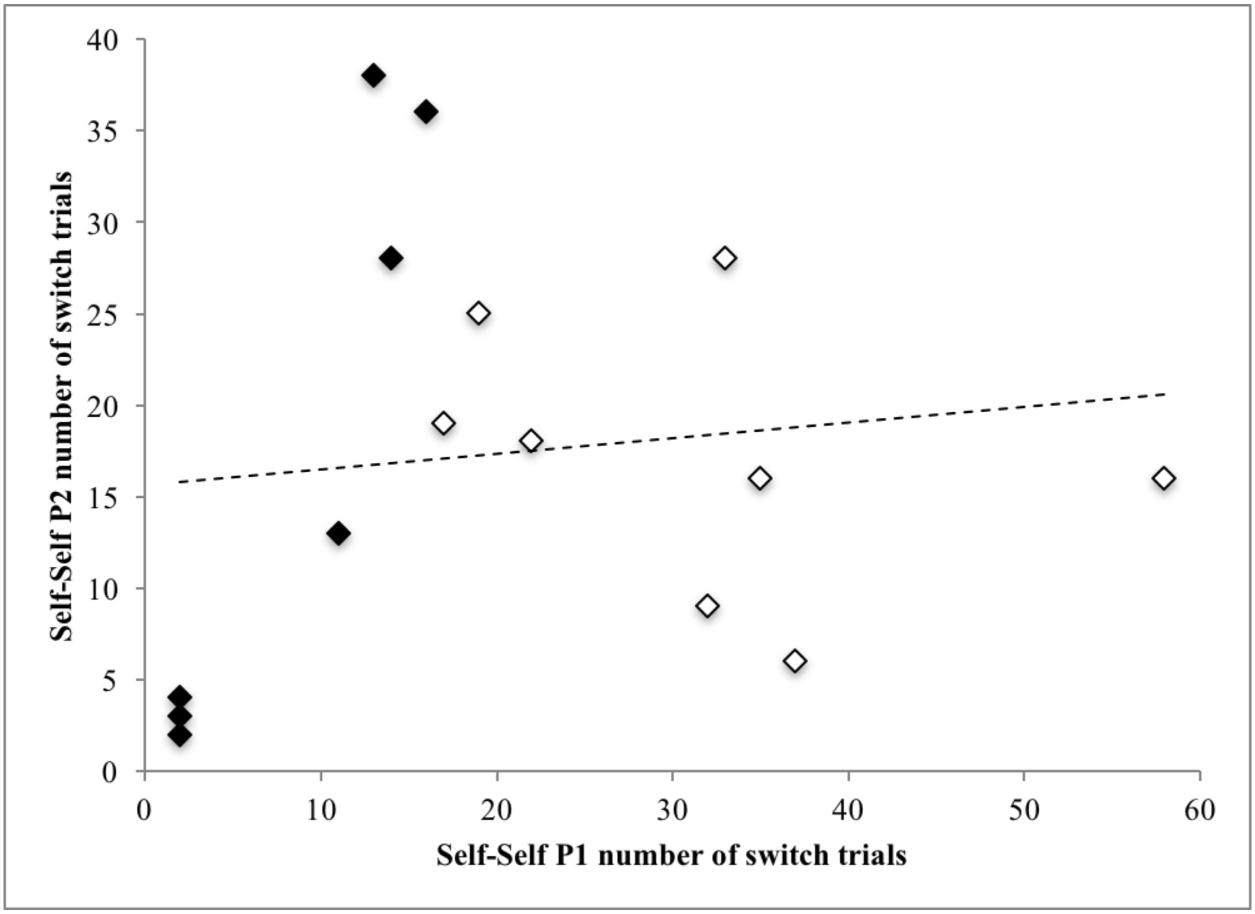

Self-Self P2 number of switch trials
Self-Self P1 number of switch trials
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60

Fig 3A

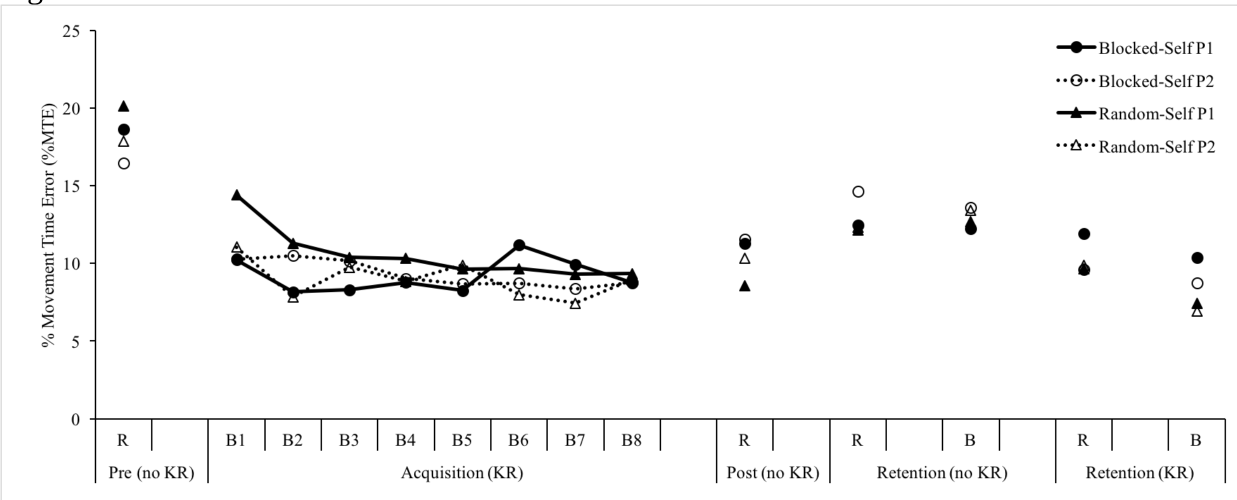
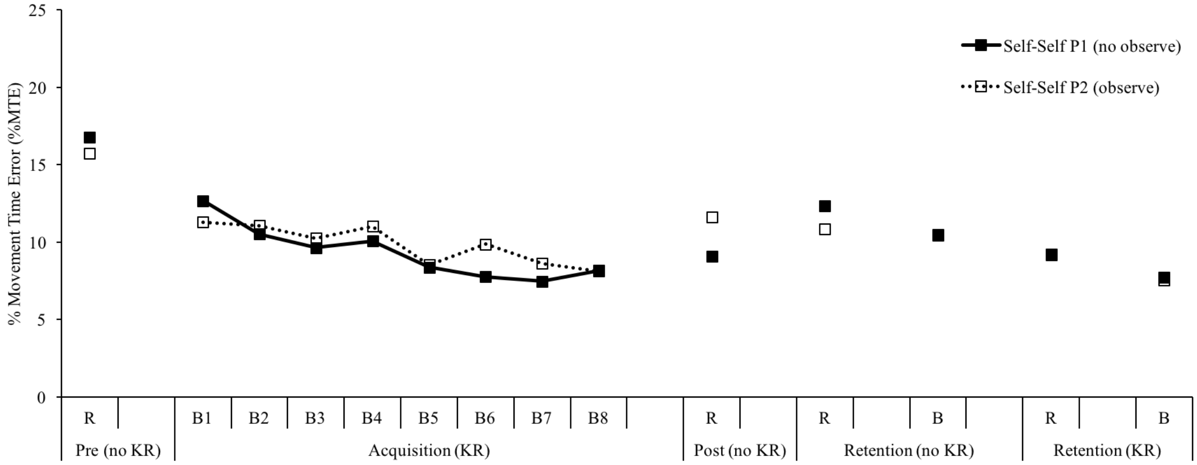

25
20
15
10
5
0
% Movement Time Error (%MTE)
Blocked-Self P1
Blocked-Self P2
Random-Self P1
Random-Self P2
R
B1
B2
B3
B4
B5
B6
B7
B8
R
R
B
R
B
Pre (no KR)
Acquisition (KR)
Post (no KR)
Retention (no KR)
Retention (KR)

Fig 3B


% Movement Time Error (%MTE)
0
5
10
15
20
25
Self-Self P1 (no observe)
Self-Self P2 (observe)
R
B1
B2
B3
B4
B5
B6
B7
B8
R
R
B
R
B
Pre (no KR)
Acquisition (KR)
Post (no KR)
Retention (no KR)
Retention (KR)