Learning together: Observation and other mechanisms which mediate shared practice contexts

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The study of how people perform and are influenced by each other when in pairs or groups has begun to receive significant attention in performance contexts. In this chapter we review some of this literature with the aim of determining if and how partners impact each other's learning of movement skills. We consider literature pertaining to the topic of what has been termed dyad learning and its effects when individuals alternate turns practicing and watching, when they practice different tasks at the same time, when they share in different components of the same task, and also when another partner organizes practice for their peer learner. We review empirical evidence from our own laboratory and from other's pertaining to the efficacy and efficiency of such social learning conditions. Because this work is relatively new and the literature somewhat mixed regarding the efficacy of paired practice for learning, we make some tentative suggestions for how practice environments in sports might be best structured to aid learning in pairs or groups.

Introduction

Imagine you are practising your yoga moves, does it help or hinder your performance and learning to be doing this in a group or with a partner? What about playing bocce (or lawn bowling) or golf with a friend? Does it matter how they perform, does this cause adjustments in your own behaviour, as if their errors were your own? Should practice contexts be designed with this potential 'interference' in mind and do shared practice contexts have a positive influence on learning when performance is required alone? For sports that have multiple skills (such as a lob, backhand, and forehand in tennis), could partners be used to encourage good practice decisions regarding how best to organize the practice of these skills to bring about effective learning and transfer to competition? In short, are there efficiencies to be gained from practise in pairs or in groups, what are the potential trade-offs in terms of learning and/or are there potential gains to be had from practising with a partner? In this chapter, we review a relatively new body of literature pertaining to social motor learning contexts that may have relevance to sports training. Because the literature on this topic is sparse and in some cases, conflicting, answers to these questions are not easy to give. However, we do make some recommendations based on the current state of knowledge (see **Table 1**). Our primary aim in this chapter is to review studies and methods where this topic of shared motor learning has been addressed and to identify areas where more research might be fruitful.

<insert Table 1 here>

Individual training sessions have typically been considered the most beneficial way to train people. For researchers, individual training sessions allow control over the learner's practice experience and the experimental variables of interest, while for practitioners, these sessions allow undivided attention towards the individual client, who in turn is free from peer-related distractions

(Shea, Wulf, & Whitacre, 1999). Social practice conditions, particularly practice in pairs (also known as dyads), have received empirical investigation in more recent years, due in part to potential efficiencies that can be gained from sharing practice. A variety of forms of social practice have been studied and we have organized this review based on the type of paradigm used. We include a summary diagram to illustrate the various forms of paired practice that have been studied along with a brief description of each (see **Figure 1**). This diagram guides how the chapter is sectioned and affords a look-up reference for terms. We have also included a table in which we provide key references for each paired practice method discussed (see **Table 2**).

<insert Figure 1 and Table 2 here>

The focus on how people perform together has been heavily influenced by research into what has been termed "joint action" (for a detailed review of this literature, see Eskenazi, van der Wel, & Sebanz, 2012). The topic of social performance has been studied and appreciated for many years (e.g., social facilitation, Zajonc, 1965; for a review, see Strauss, 2002). Psychological issues with respect to competition and motivation continue to be studied with respect to group performance (see Stanne, Johnson, & Johnson, 1999). In this chapter, we only briefly touch on some of these psychological processes as they relate to motor learning.

Four potential factors impacting paired practice

1. The opportunity to engage in discussions with co-learners can, in some cases, enhance motor learning. Opportunities for discussion seem to be particularly important for sharing knowledge/strategies that might not be easily seen. During the training of a video game ("Space Fortress"), three general discussion orientations were noted: advice; social comparison; and motivation. These peer discussions resulted in enhanced learning compared to no-discussion controls (Prislin, Jordan, Worchel, Semmer, & Shebilske, 1996). Discussion of strategy in

particular predicted final individual motor performance. For challenging tasks, sharing strategies might increase the learner's sense of responsibility for, and involvement in, the training process (McNevin, Wulf, & Carlson, 2000).

2. A second reason paired training might impact learning relates to the opportunity for social comparisons. Social comparisons have been shown to be important for group members with low-to-average levels of motivation (Prislin et al., 1996). It is likely that more motivated learners are less in need of social comparisons to encourage effort and augment performance. For less motivated individuals, perceiving oneself to be worse than peers may actually be motivating, triggering a desire to keep up with peers, in line with the self-awareness and/or the self-presentational theory of social facilitation (Rhea, Landers, Alvar, & Arent, 2003). Practicing with a peer might impact on motivation by adding a sense of competition, prompting learners to set goals and to perform closer to (or better than) their peers (McNevin et al., 2000; Rhea et al., 2003).

3. A third factor impacting paired practice effects relates to the opportunity for, and benefits of, rest. Resting between practice trials (called "distributed" or "spaced" practice) confers learning benefits for individuals, compared to more "massed" practice conditions (see Donovan & Radosevich, 1999). When this rest time is controlled in studies, paired practice benefits are not always evident (e.g., Karlinsky & Hodges, 2018b; cf. Shea et al., 1999).

4. Finally, the advantages of paired practice are most often attributed to the opportunity for observational learning, whereby a co-learner serves as a learning model for the other (e.g., Granados & Wulf, 2007; McNevin et al., 2000; Shebilske, Regian, Arthur, & Jordan, 1992). Watching the skill acquisition process allows the observer to engage in cognitive activities akin to the learner, including performance evaluation, error detection, and consideration of potential corrective responses (e.g., Adams, 1986; Black & Wright, 2000). These processes contribute to

the observers picking-up action strategies that could be used to 'solve' the requirements of the motor skill (Hodges & Franks, 2002, 2004; Horn & Williams, 2004). In addition, the observation of a motor skill is thought to trigger the action representations that are activated during the physical execution of the action (e.g., Rizzolatti & Craighero, 2004). The observation of the action during practice can generate similar neural activations and under certain conditions lead to similar adaptations in the learner as physical practice.

Overall, moderators of paired and social practice can include psychological factors, such as motivation and social comparison, and more performance-related factors such as strategy uptake through discussion and watching. In the next section, we discuss various social practice methods that have received empirical attention (as detailed in Figure 1 and Table 2).

Paired Practice Methods

Practising alongside a co-learner (i.e., concurrent practice and observation)

Part-task practice: It is common when practicing skills with complex components to break them down into simpler, easier to achieve units. Once a certain level of performance is achieved with the individual action units, they are recombined to form the whole skill. This breaking down of skills has been known as part-task practice (see Fontana, Furtado, Mazzardo, & Gallagher, 2009). In learning various swim strokes, the kick might be taught separately from the arms, or in serving in tennis, the various components (i.e., ball toss, swing, follow through) could be taught independently before being combined. The earliest research on paired practice was related to this idea of part practice with the "Space Fortress" video game (Shebilske et al., 1992; see also Jordan, 1997). Individuals alternated turns practicing only part of the task (e.g., the joystick or mouse involving different hands). This strategy was termed *active interlocked modeling*, as partners practiced together (interlocked) and they could learn from their partner before switching roles. These individuals learned to perform the entire game individually, performing as well as participants who had trained bimanually on the whole task, even though they had completed only half the physical practice on each task component and never practiced the components at the same time.

In sports, it is typical to practice an entire skill independently, even when practice is undertaken with peers (e.g., gym class, team sports). However, there are skills with distinct task components where such shared part-practice might be applicable, such as in dance where the lower and upper body have different demands, or practising the four components of the triple jump (i.e., run up and hop, or hop and jump, or the jump and take-off). Although volleyball is slightly different, the sharing of practice with a partner bumping and setting or setting and spiking could have similar applications when both skills need to be acquired.

There is evidence that individuals do not benefit equally by sharing task demands. When tasked with lifting and balancing an object, only the “worse” partner benefited from acting together relative to performing the whole task alone (Mojtahedi, Fu, & Santello, 2017). If individuals show similarity in performances when acting alone, this has benefits when acting together (see Wahn, Karlinsky, Schmitz, & König, 2018). Similar analyses might be useful in paired learning research, to help determine factors underpinning paired practice efficacy.

Whole-task practice: There are many physical activity contexts where individuals practice simultaneously with co-learners or with more accomplished performers (for research into the topic of learning versus expert models, see Pollock & Lee, 1992; Rohbanfard & Proteau, 2011). Consider for example, yoga, dance, and martial arts or team-based sports where drills are performed at the same time. In such scenarios, how does what you see influence how you perform and learn? It appears that concurrent observation when physically performing can both enhance or interfere with how actions are later retained. A series of experiments have been performed using transcranial magnetic stimulation (TMS) to probe brain (re)organization following repetitive practice of simple thumb movements (Celnik et al., 2006). Observing actions in the same direction as the movements being trained enhanced short-term motor adaptation, whereas observing actions in the opposite direction interfered with adaptation relative to physical or observational practice alone (Stefan, Classen, Celnik, & Cohen, 2008). The amount of adaptation was positively related to changes in the excitability of the motor system during action observation (Ray, Dewey, Kooistra, & Welsh, 2013). These data suggest that the responsiveness of the action observation and motor systems may predict the amount of adaptation that occurs during observational learning. Although not a complex sport skill, this research shows that executing and observing similar movements at the same time can aid in making adaptations to existing skills, likely as a result of the simultaneous activation of the same action representations in the brain.

The finding that simultaneous observation of a different movement to that being performed interferes with learning is consistent with a phenomenon known as "motor contagion" (Blakemore & Frith, 2005; Schütz-Bosbach & Prinz, 2007). The motor contagion effect is evident when the ongoing execution of a movement is disrupted by the simultaneous observation of a different movement. The motor system of the observer involuntarily represents (is "contagious" to) the actions of another. For example, when a person is cyclically moving their arm up-and-down, there is more side-to-side deviation in the movement when the actor is simultaneously observing another person making side-to-side rather than up-and-down movements (e.g., Kilner, Paulignan, & Blakemore, 2003). Watching another person's movements can elicit unintentional behavioural responses even when the observer is asked to stand still (e.g., tilting along with an unstable gymnast on a balance beam; see Sebanz & Shiffrar, 2007; Tia, Paizis, Mourey, & Pozzo, 2012).

In another sport-related example, watching one's own movements in a mirror-like display whilst running on a treadmill resulted in contagion-like interference (reflected in foot-placement and physiological markers of efficiency) when this image was reversed in the left-right dimension, in comparison to the typical mirror-image (Eaves, Hodges, & Williams, 2008). This motor contagion effect, in which the actor inadvertently adopts the movements they are watching, is thought to emerge because the action representations generated when the person observes another person's movements compete (Hommel, Müssler, Aschersleben, & Prinz, 2001; Prinz, 1997).

While it is clear that concurrent action observation can affect motor behaviour, this line of research has been largely limited to the immediate effects on action production, rather than on long-term retention. Although motor contagion effects are decreased following motor training (Roberts et al., 2016), an interesting question is whether training in the presence of visual interference, such as with a learning partner, might make people less susceptible to motor contagion during later competition. This finding is consistent with effort- or challenge-based theories of learning, whereby practice conditions that place demands on information processing (e.g., through increased interference) can impair immediate performance, but typically aid learning in the long term (see Guadagnoli & Lee, 2004; Lee, Swinnen, & Serrien, 1994).

Insight into the potential pitfalls of concurrent action observation and the importance of cognitive effort during practice was shown in a study where individuals practised the American manual alphabet. Participants either imitated the demonstrated handshapes at the same time they were shown or imitated after watching three different demonstrations (Weeks, Hall, & Anderson, 1996). Concurrent imitation facilitated performance in practice, but impaired learning compared to delayed imitation. The authors suggested that the delayed imitation condition required more cognitive effort to retain and retrieve the modeled information, which promoted retention. It follows that instructors should not always perform the exercises with the class if the final performance or competition necessitates that they will not be present. Participants in group classes should be encouraged to occasionally face away from the mirror (typically present in studio spaces) and to rotate their position in the room, such as standing in the front versus the back of the class, to discourage dependency on following others. However, the sign-language task tested by Weeks and colleagues was about acquisition of the correct hand shapes, a taxing memory task, rather than one which taxed motor performance and quality of execution. For practice of tasks where individuals already know what to do, but just are not very good at doing it, it is possible that gains might be had from physically practising alongside a partner due to the sharing of information about movement quality.

To test potential costs or benefits associated with concurrent practice with a partner, participants practised balancing on two separate stability platforms, either at the same time or alternating turns (Karlinsky & Hodges, 2018b; see **Figure 2**). The concurrent practice condition was generally perceived as more interfering and more effortful, in comparison to alternating and solo practice groups and partners tended to mirror each other's movements more so than expected by chance (see also Sebanz & Shiffrar, 2007). However, there were no outcome differences between the groups. Because the partners were similarly (un)skilled and performing the same task, there may not have been much information to gain, nor likelihood of interference in practice. Pairing one partner with a purposefully wobbly peer or more experienced partner might be one method to better test for paired practice effects.

<insert Figure 2 here>

Taking turns with a co-learner (non-concurrent practice and observation)

Alternating practice of a single skill: A form of paired practice that is frequent among partners or sports teams is to take turns. Considering that physically and/or cognitively complex skills often require breaks between trials, observing a partner during these natural rest intervals offers a prime opportunity for learners to remain engaged in practice-relevant processing while still allowing for recovery time (Shea et al., 1999).

Alternating practice (with allowed discussion) was shown to be more effective than pure physical practice in a study requiring learning to balance on an unstable platform where pairs alternated between physically practicing and observing on each trial (Shea et al., 1999). Alternating practice led to lower error than individual practice in a delayed retention test completed alone the next day (see **Figure 3a**). This alternating group outperformed a non-alternating, paired-control group, which received the same amount of physical practice and observation trials, but in a blocked format (with discussion at the end of practice).

As discussed above, in a replication of the alternating practice protocol used by Shea et al. (1999), again using a stability platform, alternating practice did not lead to performance/learning gains, when compared to just physically practising alone (see **Figure 3b;** Karlinsky & Hodges, 2018b). Because we did not allow discussion, this comparison between studies indicates that it is possible that the learning environment may be enhanced by the interactive nature of the context coupled with opportunities to share knowledge (though between task differences might also play a role too). This conclusion, however, is in contrast to results from a different study involving a cup-stacking task and alternating practice protocols where discussion was not an important variable (Granados & Wulf, 2007). It seems that observing a partner in between trials, or potentially at any time during practice can be a potential mechanism for paired-practice benefits, but that this is likely moderated by the task. Although watching a partner in between practice attempts can potentially confer benefits, it does not guarantee benefits. Because training two people at once might be more efficient than training individuals separately and because we did not see any costs associated with this method, then this seems like a viable method to use in applied practice. Related to this conclusion, there is evidence (from a computer-based task) that fewer individual physical practice trials are needed in a paired context, for learning to reach a similar level than that achieved by 100% physical practice (Shea, Wright, Wulf, & Whitacre, 2000, Experiment 2). Efficiencies in practice seem to be the most likely advantage to be gained from this type of alternating paired practice.

Alternating practice of different skills: It is often the case that sports require the athlete to perform multiple skills, such as different types of serves or return strokes in tennis or different shots or passes in sports such as basketball or hockey. There is considerable evidence that scheduling practice of these skills in a more random rather than repetitive fashion within a practice session promotes long-term learning (termed the "contextual interference" (CI) effect; see Lee, 2012). The CI effect captures the paradox that, although repetitive practice of the same skill is associated with better performance during practice, switching between different skills in practice typically results in better skill retention and transfer. Because practice often takes place in a shared environment, with other teammates or learners, the question of how the practice schedule or degree of between-skill "interference" in the practice of teammates influences the performance and learning of other people around them is an interesting and important one. For example, basketball players might practice lay-ups, jump shots, and free throws, while sharing a hoop with teammates.

Although there has been little study of multi-skill learning in pairs, one method which has been used to bring about between-trial interference is to intersperse practice attempts with demonstrations of different skills. Demonstrations showing the next skill to be practised (i.e., the same or matched skill) would cause the practice schedule of the performer to become more blocked/repetitive. Under matched demonstration conditions, performance during practice was enhanced but retention was impaired (Lee, Wishart, Cunningham, & Carnahan, 1997; Simon & Bjork, 2002). In contrast, demonstrations which were different to the next skill being practiced (i.e., mismatched), impaired performance in practice but enhanced retention (Simon & Bjork, 2002). Therefore, what happens between trials – in this case watching a matched or mismatched demonstration – impacts learning, presumably through the information processing demands imposed on the learner. This finding gives reason to suspect that a partner's practice would impact the interference experienced by a learner or teammate and ultimately how well he/she learns.

We recently tested this hypothesis in a paired learning context, where participants practiced two golf-putting skills in alternation (Karlinsky & Hodges, in review). Partners performed the same skill ("matched") or different skills ("mismatched") to their partner on consecutive trials. We controlled the schedule of practice on an individual level, so that all matched and mismatched partners practised in a semi-blocked schedule of practice, switching to a new putter every six trials. Isolating between-person interference through paired, alternating practice conditions did not result in group differences in either practice or retention. However, pairs showed an influence of their partner on actual putting errors. If their partner shot long, then the other partner showed an increased chance of shooting under (and vice versa). This compensatory behaviour was shown both on a within-person and between-person level on about 70% of the trials and did not depend on group. Therefore, partners impact each other, but they do so in a relatively benign way that, at least in this study, did not impact learning.

Although the lack of outcome effects questions the efficacy of this paired practice method to bring about (between-person) CI effects and ultimately improvements in learning, there remains a number of differences between this study and previous work where interspersed "perfect" (or expert) demonstrations were given (cf. Lee et al., 1997; Simon & Bjork, 2002). These differences could relate to any of the following additional factors that covaried between studies: i) skill complexity (e.g., Guadagnoli & Lee, 2004; Wulf & Shea, 2002); ii) observation of a learning model as opposed to a perfect demonstration (e.g., Lee et al., 1994); iii) the relatively hybrid interference schedule for pairs in this study in comparison to fully blocked or random schedules in previous work (Lee et al., 1997; Simon & Bjork, 2002); and iv) motivational benefits associated with social practice contexts (e.g., Lewthwaite & Wulf, 2012). In future research, it will be important to elucidate which of these factors do, or do not, affect learning in independent and interactive ways. For now, we know that partners impact the behaviours of their co-learners, but that the additional variability that partners introduce into practice needs to be carefully weighed. It must be sufficiently "interfering" (e.g., putting long whilst another partner putts short) or not too varied, particularly if the skills that are being acquired are relatively difficult and already have significant inherent variability.

Being in control of your own practice in paired learning situations

Self-directed practice: In the motor learning literature, there is significant interest in the effects and mechanisms of *self-directed* practice. Learners who are allowed to control their practice might decide when to receive feedback (e.g., the speed of their pitch in baseball), when to switch between practice of several skills (e.g., from practicing a float serve to a topspin serve in volleyball), or when to use a physical assistance device (e.g., a kickboard in swimming). Both motivational (e.g., Lewthwaite & Wulf, 2012) and information-processing mechanisms (e.g., Carter, Carlsen, & Ste-Marie, 2014) are thought to underlie self-directed (vs. teacher/coach-directed) practice benefits. The former explanation builds on arguments that the opportunity to exercise choice is generally autonomy-supportive and intrinsically rewarding, serving to enhance motivation and catalyze learning. The latter explanation is more closely tied to the processes underpinning learners' decision-making, such as performance evaluation, detection and correction of error.

With respect to shared practice contexts, ourselves and others (e.g., Karlinsky & Hodges, 2014, 2018a; Wulf, Clauss, Shea, & Whitacre, 2001) have studied how practice choices under such self-directed conditions are impacted by practice partners. A partner can influence both the motivation to learn and perform well (perhaps through comparisons, shared rewards, competition) as well as practice choices and processing of errors (e.g., a high error in your partner's practice attempt might lead you to a decision to repeat practice of that skill). This enhanced motivation to do well or exert effort can indirectly affect learning through practice decisions (e.g., to repeat the same skill as a partner because they did well, and you want to do better), such that disentangling these mechanisms can be problematic.

In one study involving paired-practice conditions, one member of the pair was given control over when to use assistive devices (ski poles) to help them make wider and more fluid movements on a ski-simulator (Wulf et al., 2001). The partner was "yoked" to their partner's practice, such that they had to use the ski poles (or not) on the same trials as chosen by their partner (alternating turns). Although the partners did not differ in all outcome measures, the self-directed partners showed a movement profile which was indicative of better movement control. That is, they exerted force on the simulator at a more optimal time to gain efficiencies in control, suggestive of better attunement to task-relevant feedback. Unfortunately, there was no individual practice condition, which would allow conclusions about potential paired practice benefits. The authors suggested that self-control over when to use the poles benefitted the acquisition of movement characteristics that were difficult to pick up just from watching, and required physical practice and active awareness. In contrast, paired practice likely supports the learning of movement characteristics that are easily observable (e.g., movement amplitude and frequency). The authors did not report when the self-directed learners chose to use the assistive devices (e.g., following relatively good or poor trials), so we do not know how such decisions related or not to their own or their partner's performance.

Another method for studying how a co-learner's practice influences their partner's practice choices is through the scheduling of practice for multiple skills. In one study, partners practiced three different sequence-timing tasks and switched turns after 9-trial blocks (Karlinsky & Hodges, 2018a). In pairs, one partner followed either a repetitive/blocked practice schedule or a random practice schedule, whereas their partner could choose how to practice. Self-directed learners adapted their practice (i.e., switching decisions) based on both their partner's and their own performance. When paired with a random-schedule partner, the other partner also chose a more random practice schedule, switching between tasks in their own practice more frequently than those who practiced with a blocked-schedule partner (see **Figure 4**). This increase in switching resulted in some learning benefits on later retention tests, but importantly, this study demonstrated how practice choices of a partner directly impact the choices of others in that social context (in both positive and negative ways).

To study more directly how a partner's task choices and performance impacts their partner, we conducted a second study where partners alternated turns on every trial (Karlinsky & Hodges, in preparation). Once again, practice with a random-schedule partner promoted more random practice in the partner (see **Figure 4**). In both paired groups, learners chose to switch to doing something different to their partner (i.e., bring in between-person CI) more often than they chose to switch to doing something different to their own previously practiced task (i.e., traditional within-person CI). This result suggests that learners attempt to leverage a peer's practice to control the difficulty of their own practice. However, different to how they perform based on their own performance, that is repeating the same task on their next turn if they performed poorly and switching to a new task when they did well, they chose to repeat their partner's task if their partner did well, yet switch to a different task if their partner did poorly. Although we are not sure why these choices were made, it is likely that there is something to learn from repeating a relatively good trial of a partner in comparison to a relatively poor trial, perhaps to try out a strategy or confirm correctness. In contrast, switching when you can perform a skill relatively well, probably reflects insight into when challenge might be best applied.

Peer-directed practice: Rather than simply watching from the sidelines when injured or sharing equipment, there might be ways to involve an observer more actively within the practice session, by allowing them to provide input into the practice of the person they are watching. This approach has the potential to aid both their own learning as well as the other person's learning. Such study of *peer-directed* practice has the potential to offer insight into the efficacy of paired-practice methods as well as motor learning theory (Karlinsky & Hodges, 2014; McRae, Patterson, & Hansen, 2015).

In a test of this peer-directed practice method, participants were paired with a peer for a sequence timing task (Karlinsky & Hodges, 2014). Within each pair, one partner (the "actor") physically practiced three sequences, each with a different timing goal. The actor either chose which sequence to practice at the start of each trial, while their partner passively observed, or the observing partner chose the sequence for their acting partner. Peers chose a similar schedule for practice as actors chose for themselves, choosing to switch between tasks after relatively good performance (i.e., low timing error). However, they were more liberal in their task switching, choosing for their partner to switch between tasks more frequently than the actors chose for themselves (which is typically shown to be a beneficial practice method). In terms of performance outcomes, there were no group differences in retention based on who made the practice decisions (i.e., self or peer). As long as practice was organized in a performance-dependent manner, learning was evidenced. Peer-directed practice was also rated as more motivating and enjoyable than self-directed practice, by both members of the pair. This increased motivation would be important for long-term engagement and impact practice amount, if not necessarily having any immediate effects on performance. Similar results have been noted for tests where learners or peers have been given control over when to provide feedback about errors/accuracy. Although peers and actors differed in when feedback was requested, actors did not differ in their actual learning outcomes (McRae et al., 2015).

In general, learners have expressed agreement with the choices of peers and although there have not been retention benefits associated with receiving peer-directed practice, generally measures of engagement, motivation, and trust are supportive of the idea that this active observation method can have some benefits for the non-acting partner (Karlinsky & Hodges, 2014; McRae et al., 2015). More research is required to assess how peers of varying experience differ in how they arrange practice and provide feedback and instruction, as this sharing of information among practice partners is easy to encourage and likely an efficient way to facilitate learning.

Other issues concerning paired practice and future directions

Learners' perceptions of paired practice

Efforts to measure motivation-related indices in the context of paired practice have been relatively limited, yet shared practice contexts clearly provide opportunities for social comparisons which could be motivating (and potentially de-motivating). Comparative feedback provided about a peer or average performance can influence competency beliefs and in some cases motor skill learning (e.g., Wulf, Chiviacowsky, & Lewthwaite, 2010; cf. Ong & Hodges, 2017). Such comparisons are typically designed to make learners perceive themselves as "better" or "worse" than others, serving to motivate and enhance learning or to demotivate and impede learning, respectively. These effects are usually based on virtual or experimenter-provided comparisons (e.g., Wulf et al., 2010). It may be that a real partner is a more valid source of information for making comparisons, potentially leading to stronger or weaker "comparative" effects. Perceiving oneself to be worse than a partner may actually be motivating in social contexts, triggering a desire to improve to keep up and/or avoid embarrassment (e.g., Rhea et al., 2003).

We know that perceptions of competence depend on the type of practice schedule individuals are assigned to follow, with learners following a repetitive versus random schedule reporting higher perceptions of competence (Simon & Bjork, 2001, 2002). Because repetitive practice is easier than random, learners overestimate their learning (Simon & Bjork, 2001, 2002). Perceptions of competence also depend on the relative ease/difficulty of practice compared to that of a partner. Higher perceptions of competence are noted for partners who practise with a random-schedule partner (a more difficult type of practice) than practice with a blocked-schedule partner (Karlinsky & Hodges, 2018a). This is likely a social comparison effect where people perceive themselves to be doing better than someone in the most challenging practice conditions (i.e., random), but not when the co-learner is in easier, blocked conditions.

Neurophysiology of paired learning

Substantial progress has been made over the last decade in uncovering regions of the brain and neural processes implicated in action observation (see Karlinsky, Zentgraf, & Hodges, 2017). However, much remains to be learned about how these neural substrates are recruited under social learning conditions. There is compelling evidence from the joint action literature that helps to anticipate the neurophysiological processes involved in shared practice. When performing a reaction time (RT) task with a partner, individuals have been shown to monitor whether it is their own or their co-actor's turn to respond (e.g., Sebanz, Rebbechi, Knoblich, Prinz, & Frith, 2007), to prepare a response even when it is their partner's turn (e.g., Tsai, Kuo, Jing, Hung, & Tzeng, 2006), and to process a partner's error as if it were their own (e.g., van Schie, Mars, Coles, & Bekkering, 2004). Such joint action paradigms could be usefully extended to paired training situations (e.g., by replacing RT tasks with novel skills and adding tests of retention). Such research could stimulate other paired learning-related questions, including differences between performing with a long-term or new partner (e.g., Kourtis, Sebanz, & Knoblich, 2010), and how skills are mentally represented based on whether they are learned (and later tested) alone or in a pair. For example, after pianists learned pieces of music bimanually and then performed only the right-hand part, corticospinal excitability of the left forearm was increased when they believed a co-actor performed the left-hand part versus no accompaniment (Novembre, Ticini, Schütz-Bosbach, & Keller, 2012).

Scaling up paired learning

Preliminary evidence suggests that increasing group size can afford additional benefits to members (although these do not increase proportionally with the size of the group). When groups of three learners practiced a speeded cup-stacking task one after another (i.e., Learner 1 completed all of their trials before Learner 2), observing two co-learners before physical practice was better than observing a single co-learner, which was in turn better than not watching anyone (Hebert, 2018). More opportunity for observation before physical practice was also associated with greater strategy pick-up/generation. The opportunity to observe two video-recorded models of different skill levels interspersed with physical practice was shown to enhance learning compared to observing a single model (Andrieux & Proteau, 2013). Whether similar benefits would arise in larger group practice settings and whether this would be due to the opportunity to observe more variable action strategies or simply the opportunity for more observation in between practice trials remains to be disentangled (see Hebert, 2018).

It is important to study how acquired skills might be specific to the partner(s) with whom they were acquired, especially if we wish to apply this research to more experienced performers in sports. For example, consider practicing a volleyball set pass or a basketball alley-oop to a particular teammate, or hockey players who practise an offensive play with the same line-mates. It is possible that after first acquiring a skill, which requires coordination with a particular peer or set of peers, that individuals will need to modify how they interact when switching to different partners (possibly leading to initial decrements in performance). This adaptation may be needed because of individual differences in each co-actors' abilities and style or approach to play. Learning to decrease one's variability could be a useful way to facilitate coordination with an action partner and potentially ease transfer to different teammates (for a review, see Vesper et al., 2017). There are also questions concerning the skill-level of a partner and whether being paired with a more or less skilled partner has positive or negative impacts on performance and ultimately learning.

Summary and Conclusions

Paired training seems to be at least as effective as individual training, while conferring some efficiency-related advantages. However, there are currently many unanswered questions with respect to when and why paired practice leads to motor learning benefits compared to individual practice. Part-task "interlocked" practice has been most robustly shown to support learning compared to individual practice, but such shared part-practice is not necessarily applicable for many sport skills. More relevant would be alternating or simultaneous, whole-task forms of practice, where learners have the opportunity to observe a partner interspersed or simultaneous with their own physical practice of a complete skill. These types of practice scenarios have not proven to be so robust to paired practice benefits. Although there is some suggestive evidence that partners influence each other's practice, and that there may be some beneficial interference conferred under some conditions (e.g., Karlinksy & Hodges, 2018a), there has not been strong evidence that for learning outcomes, paired practice is preferable to practice alone.

Researchers and practitioners should consider how peers, especially those simply observing practice, could be more actively involved in the skill acquisition process (such as through peer-directed practice), not just to the potential benefit of the observer's learning, but also as a means to provide informational (feedback) and/or motivational support to the physically active learner. There is much to be gained theoretically and practically by continued efforts to determine the factors that make paired (and team) learning a success and in future it will be important to complement behavioural measures with those probing psychological and neurophysiological processes, to provide a more thorough understanding of the mechanisms underpinning shared learning. Although we are hesitant to draw firm conclusions at this time about social-motor learning conditions, we have provided a preliminary list of recommendations in Table 1 which could be used to guide practice and further empirical inquiry.

References

Adams, J. A. (1986). Use of the model's knowledge of results to increase the observer's performance. *Journal of Human Movement Studies, 12*(2), 89–98.

Andrieux, M., & Proteau, L. (2013). Observation learning of a motor task: Who and when? *Experimental Brain Research, 229*(1), 125–137.

Black, C. B., & Wright, D. L. (2000). Can observational practice facilitate error recognition and movement production? *Research Quarterly for Exercise and Sport, 71*(4), 331–339.

Blakemore, S. J., & Frith, C. (2005). The role of motor contagion in the prediction of action. *Neuropsychologia, 43*(2), 260–267.

Carter, M. J., Carlsen, A. N., & Ste-Marie, D. (2014). Self-controlled feedback is effective if it is based on the learner's performance: A replication and extension of Chiviacowsky and Wulf (2005). *Frontiers in Psychology, 5*, 1–10.

Celnik, P., Stefan, K., Hummel, F., Duque, J., Classen, J., & Cohen, L. G. (2006). Encoding a motor memory in the older adult by action observation. *NeuroImage, 29*(2), 677–684.

Donovan, J. J., & Radosevich, D. J. (1999). A meta-analytic review of the distribution of practice effect: Now you see it, now you don't. *Journal of Applied Psychology, 84*(5), 795–805.

Eaves, D. L., Hodges, N. J., & Williams, A. M. (2008). Energetic costs of incidental visual coupling during treadmill running. *Medicine & Science in Sports & Exercise, 40*(8), 1506–1514.

Eskenazi, T., van der Wel, R., & Sebanz, N. (2012). Mechanisms of skilled joint action performance. In N. J. Hodges & M. A. Williams (Eds.), *Skill acquisition in sport: research, theory and practice* (2nd ed.) (pp. 229–246). London, UK: Routledge.

Fontana, F. E., Furtado, Jr., O., Mazzardo, O., & Gallagher, J. D. (2009). Whole and part practice: A meta-analysis. *Perceptual and Motor Skills, 109*(2), 517–530.

Granados, C., & Wulf, G. (2007). Enhancing motor learning through dyad practice: Contributions of observation and dialogue. *Research Quarterly for Exercise & Sport, 78*(3), 197–203.

Guadagnoli, M. A., & Lee, T. D. (2004). Challenge point: A framework for conceptualizing the effects of various practice conditions in motor learning. *Journal of Motor Behavior, 36*(2), 212–224.

Hebert, E. (2018). The effect of observing a learning model (or two) on motor skill acquisition. *Journal of Motor Learning & Development, 6*(1), 4–17.

Hodges, N. J., & Franks, I. M. (2002). Modelling coaching practice: The role of instruction and demonstration. *Journal of Sport Sciences, 20*(10), 793–811.

Hodges, N. J., & Franks, I. M. (2004). Instructions, demonstrations and the learning process: Creating and constraining movement options. *Skill acquisition in sport: Research, theory and practice* (pp. 145–174). New York, NY: Routledge.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences 24*(5), 849–878.

Horn, R. R., & Williams, A. M. (2004). Observational learning: Is it time we took another look? In A. M. Williams & N. J. Hodges (Eds.), *Skill acquisition in sport: Research, theory and practice* (pp. 175–206). New York, NY: Routledge.

Jordan, J. A. (1997). *The effectiveness of individual and dyadic training protocols for complex skill acquisition in Space Fortress: A meta-analysis*. (Unpublished doctoral dissertation). Texas A&M University.

Karlinsky, A., & Hodges, N. J. (in review). Manipulations to between-person contextual interference through mismatched practice of golf putting skills. *Human Movement Science.*

Karlinsky, A., & Hodges, N. J. (in preparation). Self-controlled practice schedules are modulated by a partner's practice in dyad learning.

Karlinsky, A., & Hodges, N. J. (2014). Evaluating the effectiveness of peer-scheduled practice. *Journal of Motor Learning & Development, 2*(4), 63–68.

Karlinsky, A., & Hodges, N. J. (2018a). Dyad practice impacts self-directed practice behaviors and motor learning outcomes in a contextual interference paradigm. *Journal of Motor Behavior, 50*(5), 579–589.

Karlinsky, A., & Hodges, N. J. (2018b). Turn-taking and concurrent dyad practice aid efficiency but not effectiveness of motor learning in a balance-related task. *Journal of Motor Learning & Development, 6*(1), 35–52.

Karlinsky, A., Zentgraf, K., & Hodges, N. J. (2017). Action-skilled observation: Issues for the study of sport expertise and the brain. In M. R. Wilson, V. Walsh, & B. Parkin (Eds.), *Progress in Brain Research (vol. 234). Sport and the Brain: The Science of Preparing, Enduring and Winning, Part B* (pp. 263–289). Academic Press.

Kilner, J. M., Paulignan, Y., & Blakemore, S. J. (2003). An interference effect of observed biological movement on action. *Current Biology, 13*(6), 522–525.

Kourtis, D., Sebanz, N., & Knoblich, G. (2010). Favouritism in the motor system: Social interaction modulates action simulation. *Biology Letters, 6*(6), 758–761.

Lee, T. D. (2012). Contextual interference: Generalizability and limitations. In N. J. Hodges & A. M. Williams (Eds.), *Skill acquisition in sport: Research, theory and practice* (2nd ed.) (pp. 79–93). London, UK: Routledge.

Lee, T. D., Swinnen, S. P., & Serrien, D. J. (1994). Cognitive effort and motor learning. *Quest, 46*(3), 327–344.

Lee, T. D., Wishart, L. R., Cunningham, S., & Carnahan, H. (1997). Modeled timing information during random practice eliminates the contextual interference effect. *Research Quarterly for Exercise & Sport, 68*(1), 100–105.

Lewthwaite, R., & Wulf, G. (2012). Motor learning through a motivational lens. In N. J. Hodges & A. M. Williams (Eds.), *Skill acquisition in sport: Research, theory and practice* (2nd ed.) (pp. 173–191). London, UK: Routledge.

McNevin, N. H., Wulf, G., & Carlson, C. (2000). Effects of attentional focus, self-control, and dyad training on motor learning; Implications for physical rehabilitation. *Physical Therapy, 80*(4), 373–385.

McRae, M., Patterson, J. T., & Hansen, S. (2015). Examining the preferred self-controlled KR schedules of learners and peers during motor skill learning. *Journal of Motor Behavior, 47*(6), 527–534.

Mojtahedi, K., Fu, Q., & Santello, M. (2017). On the role of physical interaction on performance of object manipulation by dyads. *Frontiers in Human Neuroscience, 11,* 1–15.

Novembre, G., Ticini, L. F., Schütz-Bosbach, S., & Keller, P. E. (2012). Distinguishing self and other in joint action: Evidence from a musical paradigm. *Cerebral Cortex, 22*(12), 2894–2903.

Ong, N. T., & Hodges, N. J. (2017). Balancing our perceptions of the efficacy of success-based feedback manipulations on motor learning. *Journal of Motor Behavior*. doi: 10.1080/00222895.2017.1383227

Pollock, B. J., & Lee, T. D. (1992). Effects of the model's skill level on observational motor learning. *Research Quarterly for Exercise & Sport, 63*, 25-29.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9*(2), 129–154.

Prislin, R., Jordan, J. A., Worchel, S., Semmer, F. T. & Shebilske, W. L. (1996). Effects of group discussion on acquisition of complex skills. *Human Factors: Journal of the Human Factors and Ergonomics Society, 38*(3), 404–416.

Ray, M., Dewey, D., Kooistra, L., & Welsh, T.N. (2013). The relationship between the immediate and short-term effects of action observation on the motor system. *Human Movement Science, 32*, 400-411.

Rhea, M. R., Landers, D. M., Alvar, B. A., & Arent, S. M. (2003). The effects of competition and the presence of an audience on weight lifting performance. *Journal of Strength & Conditioning Research, 17*(2), 303–306.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience, 27*, 169–192.

Rohbanfard, H., & Proteau, L. (2011). Learning through observation: a combination of expert and novice models favors learning. *Experimental Brain Research, 215*, 183-197.

Roberts, J. W., Katayama, O., Lung, T., Constable, M. D., Elliott, D., Lyons, J. L., & Welsh, T. N. (2016). The modulation of motor contagion by intrapersonal sensorimotor experience. *Neuroscience Letters, 624,* 42–46.

Schütz-Bosbach, S., & Prinz, W. (2007). Perceptual resonance: Action-induced modulation of perception. *Trends in Cognitive Sciences, 11*(8), 349–355.

Sebanz, N., Rebbechi, D., Knoblich, G., Prinz, W., & Frith, C. D. (2007). Is it really my turn? An event-related fMRI study of task sharing. *Social Neuroscience, 2*(2), 81–95.

Sebanz, N., & Shiffrar, M. (2007). Bodily bonds: Effects of social context on ideomotor movements. In P. Haggard, Y. Rossetti, & M. Kawato (Eds.), *Sensorimotor foundations of higher cognition: Attention and performance XXII* (pp. 267–291). New York, NY: Oxford University Press.

Shea, C. H., Wright, D. L., Wulf, G., & Whitacre, C. (2000). Physical and observational practice afford unique learning opportunities. *Journal of Motor Behavior, 32*(1), 27–36.

Shea, C. H., Wulf, G., & Whitacre, C. (1999). Enhancing training efficiency and effectiveness through the use of dyad training. *Journal of Motor Behavior, 31*(2), 119–123.

Shebilske, W. L., Regian, J. W., Arthur, W., & Jordan, J. A. (1992). A dyadic protocol for training complex skills. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 34*(3), 369–374.

Simon, D. A., & Bjork, R. A. (2001). Metacognition in motor learning. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 27*(4), 907–912.

Simon, D. A., & Bjork, R. A. (2002). Models of performance in learning multisegment movement tasks: Consequences for acquisition, retention, and judgments of learning. *Journal of Experimental Psychology: Applied, 8*(4), 222–232.

Stanne, M. B., Johnson, D. W., & Johnson, R. T. (1999). Does competition enhance or inhibit motor performance: A meta-analysis. *Psychological Bulletin, 125*(1), 133–154.

Stefan, K., Classen, J., Celnik, P., & Cohen, L. G. (2008). Concurrent action observation modulates practice-induced motor memory formation. *European Journal of Neuroscience, 27*(3), 730–738.

Strauss, B. (2002). Social facilitation in motor tasks: A review of research and theory. *Psychology of Sport and Exercise, 3*(3), 237–256.

Tia, B., Paizis, C., Mourey, F., & Pozzo, T. (2012). Do equilibrium constraints modulate postural reaction when viewing imbalance? *Brain and Cognition, 79*(2), 89–95.

Tsai, C.-C., Kuo, W.-J., Jing, J.-T., Hung, D. L., & Tzen, O. J.-L. (2006). A common coding framework in self-other interaction: Evidence from joint action task. *Experimental Brain Research, 175*(2), 353–362.

van Schie, H.T., Mars, R. B., Coles, M. G. H., & Bekkering, H. (2004). Modulation of activity in medial frontal and motor cortices during error observation. *Nature Neuroscience, 7,* 549–554.

Vesper, C., Abramova, E., Bütepage, J., Ciardo, F., Crossey, B., Effenberg, A., … & Wahn, B. (2017). Joint action: mental representations, shared information and general mechanisms for coordinating with others. *Frontiers in Psychology, 7,* 1–7.

Wahn, B., Karlinsky, A., Schmitz, L., & König, P. (2018). Let's move it together: A review of group benefits in joint object control. *Frontiers in Psychology: Cognition, 9,* 1–5.

Weeks, D. L., Hall, A. K., & Anderson, L. P. (1996). A comparison of imitation strategies in observational learning of action patterns. *Journal of Motor Behavior, 28*(4), 348–358.

Wulf, G., Chiviacowsky, S., & Lewthwaite, R. (2010). Normative feedback effects on learning a timing task. *Research Quarterly for Exercise & Sport, 81*(4), 425–431.

Wulf, G., Clauss, A., Shea, C. H., & Whitacre, C. A. (2001). Benefits of self-control in dyad practice. *Research Quarterly for Exercise & Sport, 72*(3), 299–303.

Wulf, G., & Shea, C. H. (2002). Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychonomic Bulletin & Review, 9*(2), 185–211.

Zajonc, R. B. (1965). Social facilitation. *Science, 149*(3681), 269–274.

Table 1: Recommendations for applying good practice principles to the design of social learning contexts

1. To increase efficiency in training, two people can be trained at the same time, but just on part of the task. For example, in volleyball, one person receives and feeds the ball through a bump to their partner (the setter), who in turn practises setting. Or the setter practises setting the ball for the spiker. In soccer, this might be practising throw-ins whilst a partner practises controlling the ball.
2. Taking turns practising with a partner helps when there are various strategies or components which could be conveyed by watching another co-learner (e.g., how to take a penalty kick in soccer, how to perform a long-jump in track and field).
3. When people have to practice multiple skills within a certain sport (e.g., lay-up, free-throw, and jump shot in basketball), variability in the ordering of these skills is a good way to practice. Partners can be a good source of (between-person) variability in practice and they can also help encourage variability in their partner's practice. Beware though, the opposite can also occur if a partner engages in a more rote, repetitive type of practice, as bad practice habits can be transmitted.
4. Practising with a partner who is instructed to bring variability into how they practice provides exposure to good practice principles while allowing autonomy to be maintained in the practice decisions made by the co-learner. The sharing of good practice habits in this more "implicit" manner might help support good quality practice in future episodes.
5. Partners help to encourage motivation and engagement through social connectedness. This could be manifest through increased attention or competition/effort.
6. To get the efficiencies in practice, but not trade-off effectiveness, make sure that the co-learner is engaged during the passive phase (observation). Try to keep partners attending through instructions, constant monitoring, shared practice goals, rewards, or promise (threat) of future testing.
7. If the task itself requires performance in pairs or groups, then there are transfer benefits associated with practising in this way (i.e., get used to practicing the way you will play).
8. There can be costs associated with watching someone else, which might be evidenced in compensation for other's errors. This may be a good way of practising if the test or competition conditions are similar, as it could build up resilience to contagion/ interference.
9. When you are practising sports that are easily fatiguing, then alternating practice with a partner could facilitate learning by co-opting the rest periods for observation (e.g., relay in swimming, taking turns hitting or pitching in baseball). These rest periods are important for motor learning even when unfilled.
10. If you're in a paired situation, with a partner of a similar skill level, it can be like having a mirror on your own performance. You get to see what your partner is doing wrong and hence potentially learn from their mistakes.

Table 2: Summary of paired motor learning studies

Paradigm + Description	Sample references	Skill(s) practiced	Experimental groups	Summary of retention results
PRACTISING ALONGSIDE A PARTNER -- CONCURRENT PRACTICE AND OBSERVATION				
Part-task practice Partners practice complementary parts of the whole skill at the same time	Shebilske et al. (1992)	Space Fortress computer game	-Individual (bimanual practice) -Dyad-part (unimanual practice)	No differences between individuals and pairs, despite pairs receiving half the physical practice trials and never practicing the task components together.
Whole-task practice Partners practice a whole skill at the same time	Karlinsky & Hodges (2018b)	Balance platform	-Individual -Concurrent pairs -Turn-taking pairs	No differences between individuals and pairs or between pair groups.
TAKING TURNS WITH A PARTNER -- NON-CONCURRENT PRACTICE AND OBSERVATION				
Alternating practice of a single skill Partners take turns physically practicing and observing one another practice a single skill	Granados & Wulf (2007)	Cup-stacking	-Observation/Discussion -Observation/No Discussion -No observation/Discussion -No observation/No discussion	Groups allowed to observe a partner's practice were better (faster) than those who could not observe. No differences between the with-observation groups or between the no-observation groups.
	Shea et al. (1999)	Balance platform	-Individual -Turn-taking pairs -Paired-control (partners switched turns halfway through practice session)	The turn-taking group performed with lower error than the individual and paired-control groups. The latter groups did not differ.
Alternating practice of multiple skills Partners take turns physically practicing and observing one another practice more than one skill	Karlinsky & Hodges (2018a)	Keystroke sequences	-Blocked-schedule partner + Self-controlled task-switching partner -Random-schedule partner + Self-controlled task-switching partner -Self-controlled task-switching + Self-controlled task-switching (only one partner could observe the other)	Random pairs had lower timing error than blocked pairs on the post-test and 1 of 4 delayed retention tests. No differences between self-controlled partners who observed vs. did not observe the partner's practice.
	Karlinsky & Hodges (in review)	Golf putting	-Actor + Observer (passive) -Matched turn-taking pairs -Mismatched turn-taking pairs	Actors were more accurate than Observers. No differences between Actors and pairs or between pair groups.
Actor + Observer The "actor" physically practices while an "observer" watches (either passively or with some control over the actor's practice)	Karlinsky & Hodges (2014)	Keystroke sequences	-Actor (self-controlled task-switching) + Observer (passive) -Actor (peer-controlled task-switching) + Observer (peer-scheduler)	Actors had lower timing error than Observers. No differences between self- vs. peer-controlled Actors or between passive vs. peer-scheduler Observers.
	McRae et al. (2015)	Keystroke sequence	-Actor (self-controlled feedback) alone -Actor (peer-controlled feedback) + Observer (peer-scheduler)	Peer-controlled Actors had lower VE (but not AE) than self-controlled Actors.

Figure captions

Figure 1. Summary diagram illustrating the various forms of paired practice which have been studied along with a brief description of each.

Figure 2. Depiction of the concurrent whole-task practice and observation condition (for study details, see Karlinsky & Hodges, 2018b).

Figure 3. Average root-mean-square-error (RMSE) in degrees on a stabiliometer balance task for the first, halfway, and final acquisition and test trials for (A) Shea et al.'s (1999) individual, turn-taking, and paired-control groups, and (B) Karlinsky and Hodges' (2018b) individual, turn-taking, and concurrent practice groups. Participants in the individual groups received only physical practice. Participants in the pair groups were provided the same amount of physical practice as the individual groups but were also able to observe their partner during practice, either interspersed with their own physical practice trials (turn-taking groups), or before or after all of their own trials (paired-control group), or while they practiced (concurrent group). All participants performed the tests individually. Data adapted from Shea et al. (1999) and Karlinsky and Hodges (2018b).

Figure 4. Mean number of trials (and *SE* bars) where self-controlled ("Self") participants switched to a different sequence, when practicing with a blocked-schedule partner, with a random-schedule partner, or alone. In Study 1, partners alternated turns after blocks of 9 trials (for details, see Karlinsky & Hodges, 2018a). In Study 2, partners alternated turns every trial (Karlinsky & Hodges, in preparation).

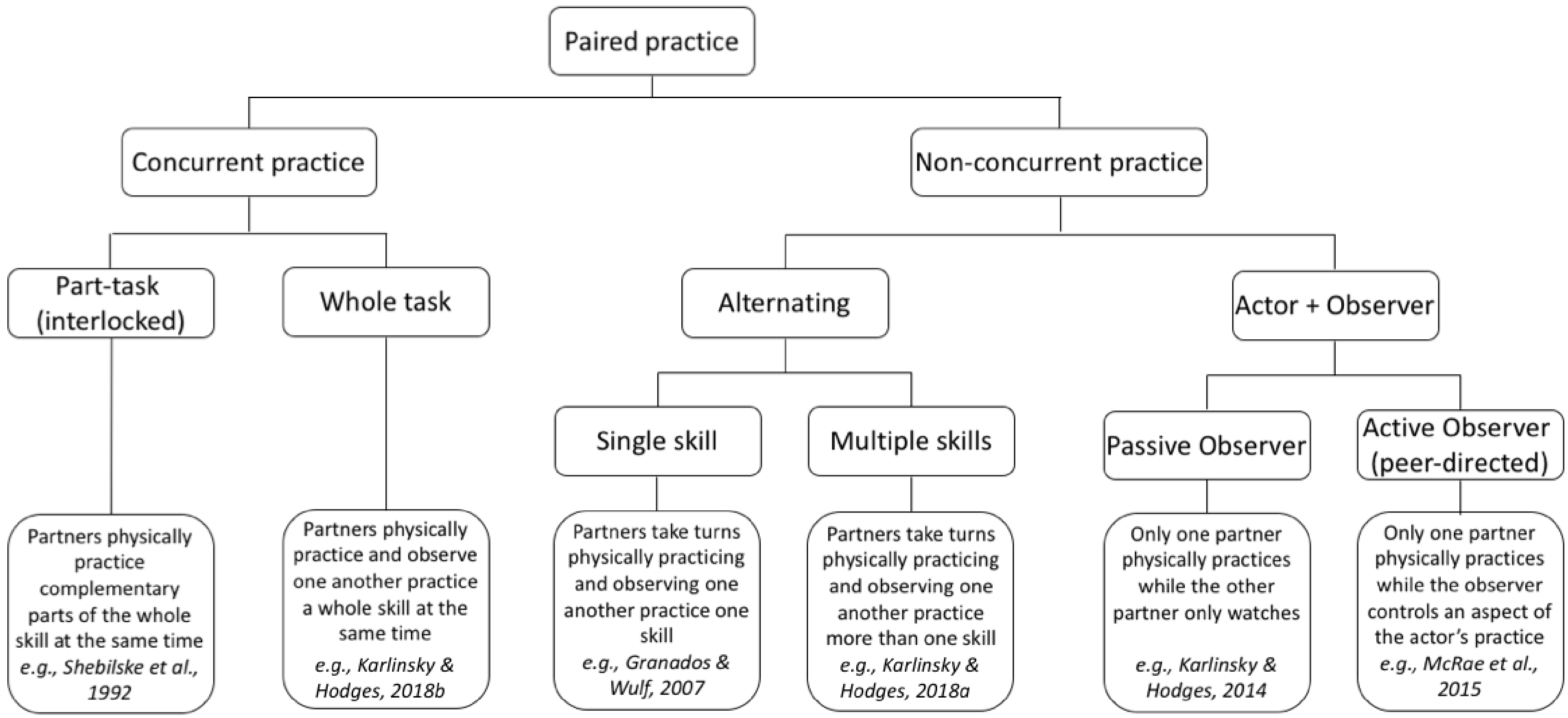
Paired practice
Concurrent practice
Non-concurrent practice
Part-task (interlocked)
Whole task
Alternating
Actor + Observer
Single skill
Multiple skills
Passive Observer
Active Observer (peer-directed)
Partners physically practice complementary parts of the whole skill at the same time e.g., Shebilske et al., 1992
Partners physically practice and observe one another practice a whole skill at the same time e.g., Karlinsky & Hodges, 2018b
Partners take turns physically practicing and observing one another practice one skill e.g., Granados & Wulf, 2007
Partners take turns physically practicing and observing one another practice more than one skill e.g., Karlinsky & Hodges, 2018a
Only one partner physically practices while the other partner only watches e.g., Karlinsky & Hodges, 2014
Only one partner physically practices while the observer controls an aspect of the actor's practice e.g., McRae et al., 2015

Figure 1.

Figure 2.

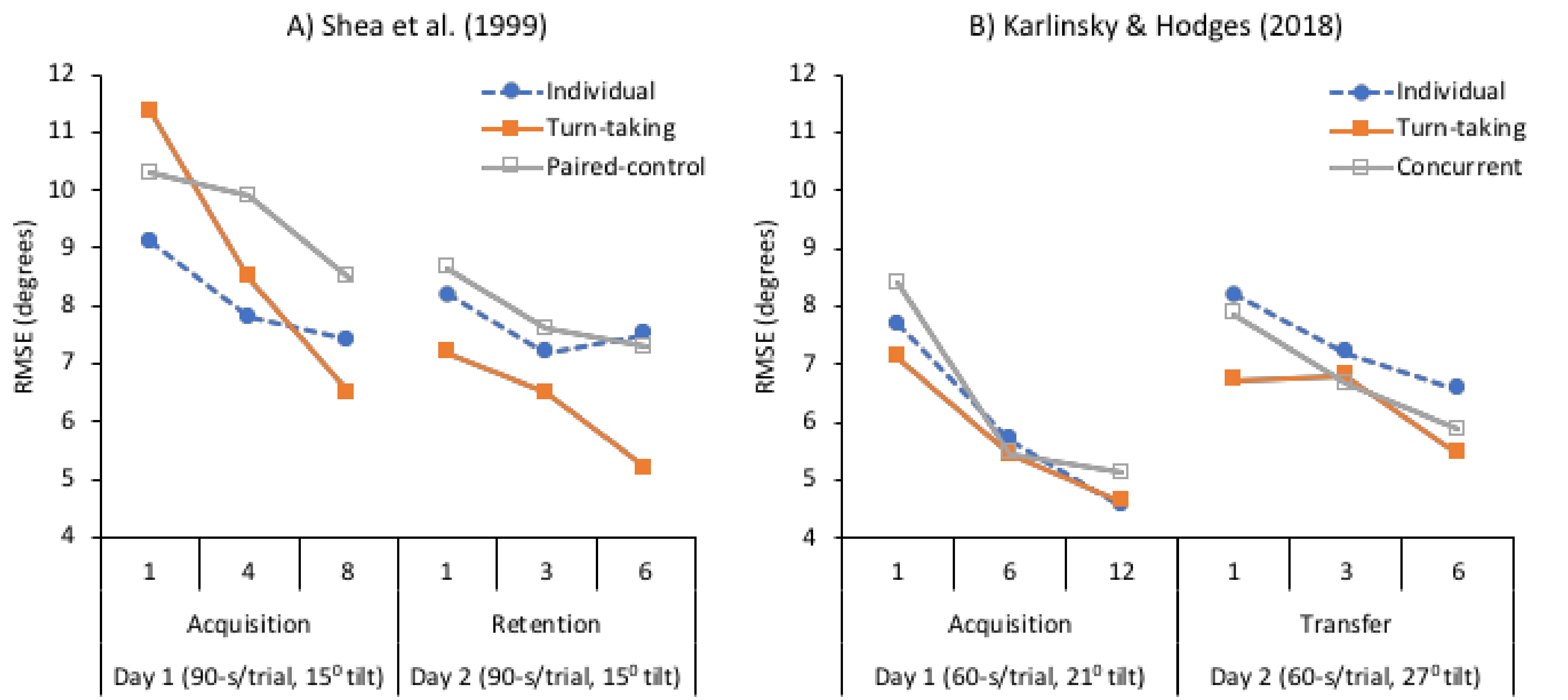
A) Shea et al. (1999)
B) Karlinsky & Hodges (2018)
RMSE (degrees)
12
11
10
9
8
7
6
5
4
Individual
Turn-taking
Paired-control
Concurrent
1
4
8
3
6
12
Acquisition
Retention
Transfer
Day 1 (90-s/trial, 15⁰ tilt)
Day 2 (90-s/trial, 15⁰ tilt)
Day 1 (60-s/trial, 21⁰ tilt)
Day 2 (60-s/trial, 27⁰ tilt)

Figure 3.

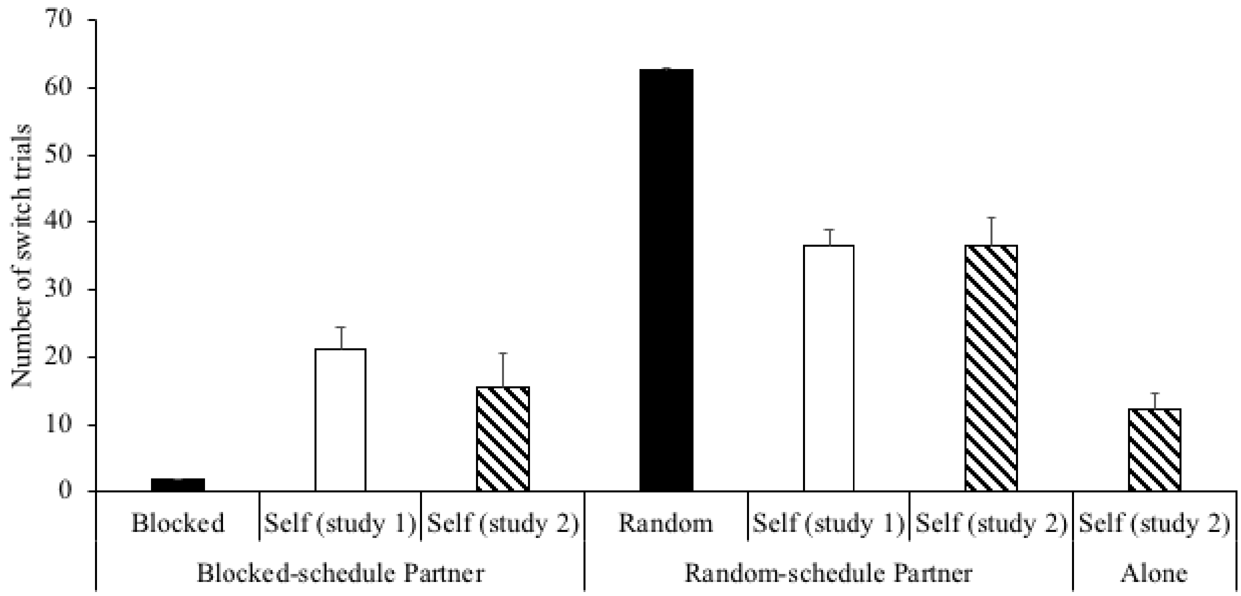
Number of switch trials
0
10
20
30
40
50
60
70
Blocked
Self (study 1)
Self (study 2)
Random
Self (study 1)
Self (study 2)
Self (study 2)
Blocked-schedule Partner
Random-schedule Partner
Alone

Figure 4.