Difficulty is a Real Challenge:

A Perspective on the Role of Cognitive Effort in Motor Skill Learning

Word count: 3494 (main body, not including abstract, figures and references)

Abstract

Desirable difficulties for learning have been supported by research in motor skill acquisition and incorporated into a challenge-related framework. Numerous lines of research show that practice conditions that increase cognitive effort best support learning, which has been seen clearly in the contextual interference effect where randomly-ordered practice of skills hinders performance (relative to blocked), but aids long-term learning. Here we outline three lines of research that show results inconsistent with the desirable difficulties framework or that help identify such difficulties. We consider research related to success perceptions, implicit motor learning, and practicing with a partner. Based on these data, we argue that desirable difficulties for motor learning are best conceptualized as task-specific, individually-referenced processes, dependent on gradual improvements in practice and the meeting/exceeding of trial-to-trial expectations. Research directed to assessing the informational and motivational value of errors made during practice, in a dynamic fashion, should help in determining desirable difficulties.

Keywords

Motor learning, contextual interference, challenge, implicit learning, dyad practice

Difficulty is a Real Challenge: A Perspective on the Role of Cognitive Effort in Motor Skill Learning

One of the first things you are told when studying motor learning is the distinction between learning (in the long-term) and performance (in the short-term). Performance in practice reflects temporary factors and only a delayed "retention" or transfer test, usually at least 24 hours later, allows conclusions about learning (Schmidt & Lee, 2019). This distinction is critical because conditions that benefit performance during practice can have detrimental effects on learning (Kantak & Winstein, 2012). This performance-learning separation has also been captured in a motor learning framework, called the challenge point hypothesis (Guadagnoli & Lee, 2004), which is heavily based on concepts of desirable difficulties (Bjork, 1994; Bjork & Bjork, 2011), and focuses on individual differences in optimal challenge in practice needed to facilitate learning (termed functional task difficulty).

For motor skills, the "contextual interference" effect (Shea & Morgan, 1979; for review see Wright & Kim, 2019), is the poster child for performance-learning distinctions. Contextual interference is a practice order effect, where blocked-ordered (repetitive) practice of different skills (e.g., *AA-BB-CC*) typically exceeds performance noted for randomly-ordered (interleaved) practice of skills (e.g., *CB-AC-BA*), but this pattern reverses in retention tests where randomly-ordered practice promotes better learning than blocked. Similar reversals have been shown when participants practice speed or distance variations of the same skill (e.g., Aa versus AA or aa), variations in the order of those skill variants (e.g., *AaA-aAa* versus *AAA-aaa*; Wulf & Schmidt, 1988), or when participants receive assistance in the form of frequent feedback during practice (e.g., Salmoni, Schmidt, & Walter, 1984). Although the proposed mechanisms for these reversals are different, they are linked by the fact that difficulty (a property of the task; Bjork & Bjork,

2011) and cognitive effort (a property of the individual elicited by the task; Lee, Swinnen, & Serrien, 1994), are increased during practice and overcoming these challenges benefits learning. As detailed below, the Challenge Point Framework (CPF, Guadagnoli & Lee, 2004) appears to offer a common underlying mechanism for these motor learning reversal effects.

In this essay, we briefly discuss three lines of research that require us to refine our thinking about desirable difficulties during practice for motor learning. We start by summarizing the CPF, then revisit this framework at the end of the paper to reconcile some of the issues.

Challenge Point Framework

In the CPF, the difficulty of the task is conceptualized as "challenge" (Guadagnoli & Lee, 2004). "Difficulty" is a property of a task and desirable difficulties are features of practice that improve the storage and/or retrieval strength of a memory (Bjork, 1994; Kang, McDaniel, & Pashler, 2011). "Challenge" is a property of the individual interacting with the task, explained as the amount of available novel information (Guadagnoli & Lee, 2004), making challenge very similar to cognitive effort (Lee et al., 1994). This distinction between the task's inherent difficulty and the interaction of task difficulty with the individual has been characterized in the CPF as nominal and functional task difficulty respectively. The CPF has been illustrated as parallel axes relating to performance and learning, with challenge on the abscissa (see Figure 1). Two superimposed curves for performance and learning show how with increasing challenge; performance monotonically declines, whereas learning (hypothetically) shows an inverted U shape, with optimal learning at the peak. This peak occurs during the performance decline, but the exact location is unknown. Challenge is specific to the skills of the learner, so each learner's optimal challenge point (or zone) is different.

Three Findings from Motor Learning that Inform or Challenge the Concept of Desirable Difficulties

Results from experiments on perceptions of success and implicit learning pose problems for traditional accounts of difficulty during practice. Empirical research into shared practice conditions raises questions about whether adding a partner creates a desirable difficulty in practice, suggesting boundary conditions on sources of desirable difficulties. We consider these three lines of research and discuss ramifications of these data for practice principles.

Problem 1: If difficult practice conditions make people think they are not learning (much), can this be reconciled with research showing that perceptions of success aid learning?

Judgements of learning (JOLs) require learners to estimate how they will perform in the future, providing perceptions of learning. JOLs were studied in sequence timing tasks that showed dissociations between perceptions of success and actual success (Simon & Bjork, 2001, 2002). Participants who practiced different tasks under blocked-ordered (easier) conditions had less accurate JOLs (overconfidence in performance on delayed tests) in comparison to participants in randomly-ordered (harder) conditions.

JOL dissociations suggest that the ease with which information is retrieved at present shapes judgements of later recall, even though these judgments might be poor (Bjork, 1998). However, there is work showing that low perceived competence negatively impacts learning compared to higher perceived competence. Lee and Wishart (2005) noted that a negative view of one's learning could cause practice to stop or a switch to "easier" conditions. Negative perceptions of success have also been directly linked to negative learning outcomes (Wulf & Lewthwaite, 2016). For example, golf putting to small targets led to fewer successes and lower reported competence after practice compared to putting to larger targets at the same distance (Palmer, Chiviacowsky, Wulf, 2016). In delayed tests (> 24 hrs later), without the target circles, the more "successful" groups (large target in practice) were more accurate. Although indices related to cognitive effort were not collected, aiming to smaller targets is more effortful with respect to motor planning than larger targets, as observed by slower pre-movement aiming times (e.g., Ong, Hawke & Hodges, 2018). Success-related target size results have in part been explained by reward-expectation signals and biochemical processes associated with dopamine, which consolidate motor memories (e.g., Ma, Pei, & Meng, 2017).

These success data and associated theory (Wulf & Lewthwaite, 2016) conflict with the JOL findings in contextual interference (CI) studies. How can “easier” practice (and higher competence) lead to better learning? This lack of coherence is not easily resolved. It might be related to management of expectations, varying informational and motivational value of errors in practice, or the relative size of learning effects related to success perceptions versus practice difficulty. Doing as well or better than expected in randomly-ordered practice, could lead to lower JOLs compared to blocked, but because expectations are met or exceeded, overall competence perceptions do not negatively impact learning. Errors in practice have both informational and motivational effects, which may conflict in value to overall learning. When conditions are challenging (or perceived challenging), errors might also be perceived more positively, than when conditions are low or too high in challenge. It is important to consider how errors of the same magnitude might be evaluated differently depending on a learner’s expectation for such errors and the definition of success in the task. Finally, learning effects associated with target size and success perceptions have not been consistently observed (e.g., Ong, Lohse & Hodges, 2015), suggesting that perhaps the effects are small or that they interact with many individual and task factors as detailed above. Ultimately, more work is needed to understand the potentially complex relationship that exists between the difficulty of practice and perceptions of success to ascertain their impact on learning.

Problem 2: Can desirable difficulties, the value of errors, and claims about cognitive effort be reconciled with research on implicit motor learning?

One of the dilemmas in motor learning is how to align the importance of cognitive effort with research showing that reducing explicit cognition is actually beneficial for learning. There is a body of research showing the benefits of implicit motor learning over more explicit forms of instruction, feedback, and practice conditions that promote accrual of explicit knowledge (Masters, van Duijn, & Uiga, 2019). Some of these implicit learning paradigms use a progression from easy-to-challenging task difficulty (Poolton, Masters, & Maxwell, 2005), use instructional analogies rather than detailed explicit instructions (Lam, Maxwell, & Masters, 2009), or withhold instructions (Zhu et al., 2011), in order to reduce explicit cognition and knowledge during practice. Across these studies, authors have argued that reducing explicit cognition during practice promotes learning that is durable across time and transferable (especially to high-pressure situations).

At the surface, implicit motor learning benefits appear inconsistent with the desirable difficulties' literature (i.e., CI is a desirable difficulty specifically because it requires increased cognitive effort during practice). To reconcile these findings, it is important to consider what specific processes are engaged when we talk about "effort". For instance, Rendell, Masters, Farrow, and Morris (2010) showed that a randomly-ordered (rather than blocked-ordered) practice of two sports skills led to slower probe reaction times on a secondary task during practice, supporting the suggestion that randomly-ordered practice is more cognitively effortful. However, the randomly-ordered group reported decreased awareness of explicit rules following practice, such that greater cognitive effort during practice, did not lead to the accrual of explicit knowledge (see also Fuhrmeister & Myers, 2020). Therefore, although randomly-ordered practice is a desirable difficulty, it is not simply that increased cognitive effort during practice is good or that decreased cognitive effort during practice is bad. Instead, there is a need to specify what cognitive processes are desirable.

For motor skills, cognitive effort elicited by practice difficulties might be best conceptualized in terms of specific action-selection (what to do) and execution-related (how to do) processes (Erhlenspeil, 2001). Thinking about "how" to perform an action, is different from thinking about "what" to perform, with the former being disruptive for well practised skills (Beilock, Carr, MacMahon, & Starkes, 2002). In CI, processes related to the retrieval and selection of actions are beneficial for learning (Frömer et al., 2016a). The benefits of these processes contrast to the potentially detrimental effects of other cognitive processes on learning (e.g., accrual of declarative information from instructions).

Identifying specific processes that serve as desirable difficulties in motor learning is an important goal of future work. For instance, the effectiveness of "errorless" learning schedules (in which learners progress from easy-to-challenging difficulties) has been explained in the implicit motor learning field as due to the lack of declarative rules about the skills that accrue during practice (Poolton et al., 2005). However, it could be that errorless methods merely follow an appropriate progression of difficulty for novice learners, leading to more informative errors at each stage of practice (in alignment with the CPF; see also Frömer, Stürmer, & Sommer, 2016b). "Errorless" practice schedules also reduce the amount of error feedback, which could have motivational benefits (Wulf & Lewthwaite, 2016). More empirical work is needed to dissociate these explanations and identify specific cognitive processes that facilitate or hinder motor learning.

Problem 3: Are partners a desirable difficulty in shared practice contexts?

One question asked by Simon and Bjork (2002) was whether partners can bring desirable difficulty into practice. This question was prompted by studies showing that computerized (auditory and visual) demonstrations that matched one of a series of sequences to be practised on the next trial, removed or decreased CI retention advantages associated with randomly-ordered practice (Lee, Wishart, Cunningham & Carnahan, 1997; Simon & Bjork, 2002 respectively). Improvements in learning were also noted for blocked-order practice conditions when demonstrations did not match the next trial sequence (Simon & Bjork, 2002). One explanation for these effects is that cognitive operations involved in planning and retrieval were reduced (or enhanced) when same (or different) skill demonstrations were provided. Therefore, it seemed reasonable to suspect that a partner could serve the same role as these computer demonstrations, potentially acting as an external source of desirable difficulty.

To test whether CI effects could be induced (or moderated) through practice with a partner, three groups practiced golf putting skills to a target, with a seated or standing putter, alone or with partners (Karlinsky & Hodges, 2019). Partners practised the same (matched) or different skills (mismatched), alternating between trials, even though the semi-blocked practice order was the same for all groups. Contrary to expectations, the two partner groups did not differ in accuracy during practice or in later retention tests. Neither did co-learners cause “interference” or difficulty for learning, when mismatched pairs were compared to the practice alone group.

In subsequent partner studies with sequence timing tasks, again partners were not a desirable source of difficulty for learning (Karlinsky, Alexander, & Hodges, 2020; Karlinsky & Hodges, 2018). Partners did, however, influence practice decisions. When one of the pair was given choice over how to order their practice and the other practised in a random or blocked-order schedule, partners chose to bring more or less variability into practice, congruent with a partner's schedule (e.g., switching between tasks more frequently when paired with a random-scheduled partner, see Figure 2). Watching a partner conveyed a strategy and encouraged copying of the same practised task as the partner (matching), especially when the partner performed well. This copying of a partner's chosen task after "good" performance is opposite to what individuals choose to do based on their own performance, that is repeat the same task when they are not doing well (Karlinsky et al., 2020; Keetch & Lee, 2007). As such, the partner serves as a useful learning model, rather than an impediment/difficulty to cognitive operations related to planning.

Differences between choices to repeat or match a task, based on one's own performance versus a partner's performance, suggest that there are different processes guiding learning for the individual rather than between partners, in terms of task-difficulty. Indeed, in some recent timing tasks (Grieve, Karlinsky, Gowpalakrishnan & Hodges, 2020), enforced matching of a partner benefited the rate of acquisition, but did not lead to costs in retention, whereas repetition for an individual typically has retention costs. When mismatching among pairs was enforced, there was no interference, compared to alone groups, which would be expected if partners provide desirable difficulty. In summary, a partner does not appear to act as a desirable difficulty for learning, rather desirable difficulties in practice schedules are primarily associated with an individual's physical experience.

The Challenge Point Framework for Motor Learning Revisited

Frameworks like desirable difficulties (Bjork & Bjork, 2011) and individual challenge points (Guadagnoli & Lee, 2004) are useful tools for thinking about the downstream effects of practice conditions on learning. However, it is difficult to identify in advance which difficulties will be desirable and where "optimal" challenge zones lie. In this essay, we have shown how three different areas of motor learning research (perceptions of success, implicit learning paradigms, and shared practice) are either not easily reconciled in challenge-based frameworks or highlight "difficulties" not conducive for learning. Other examples could be chosen (e.g., massed versus spaced practice), but these three areas can help refine our thinking about what make difficulties desirable for motor learning. Below we present considerations for future work and for elaborating upon current frameworks of challenge and difficulty in learning.

Prospectively Selecting Difficulties

If we want to identify desirable difficulties or useful ways of increasing cognitive effort, we need to do this prospectively (see also McDaniel & Bulter, 2011). If not, we risk making circular arguments (i.e., "What makes a difficulty desirable? If it leads to better learning") and we would be forced to identify desirable difficulties through costly trial and error research. As a step in that direction, we think that difficulties are desirable when they are specific and relevant to the test. By specific and relevant we mean difficulty that engages cognitive processes that are shared with the task in competitive/real-world contexts. Progressively increasing the speed with which one must perform is beneficial if response time is constrained in competition. Hopping on one foot will make practice difficult, but likely not benefit learning.

For difficulties to be desirable, they must also promote cognitive processes that are novel, relevant and not redundant with what a learner is already doing. Asking a learner to estimate their own errors before receiving feedback will only increase difficulty and learning if the learner is *not* already attending to their errors. Partners pay attention when there is something to learn (and will copy a partner's task), but if there is nothing to learn, this potential source of difficulty is ignored. More empirical work is needed to improve our definitions and create a truly prospective model for prescribing practice difficulties. As a starting point, we think that practitioners can reasonably identify "desirable" difficulties by carefully selecting those difficulties that lead the learner to invest effort in novel task-specific processes and these difficulties should be (at least) potentially solvable by the learner (e.g., success is possible but not guaranteed nor too common). Difficulty considerations should also be designed to promote steady improvements in practice, with plateaus signalling the need for new challenge. Attaining a plateau in performance is beneficially related to consolidation of procedural memories (Hauptman, Reinhart, Brandt & Karni, 2005). Designing practice dynamically, based on an individual's performance-curve during acquisition, shows promise as a beneficial learning intervention (Porter, Greenwood, Panchuk & Pepping, 2020; Wadden et al., 2019).

Grounding "Effort" in Specific Processes

We want to clarify that by effort, we do not mean "doing the same process but more." Effort is a useful term because it conveys the experience of the learner in simple language, but scientifically "increased effort" boils down to the engagement of distinct cognitive/neural processes specific to contexts. Bjork and Bjork (2011) have emphasized this point as well, stressing that it is specifically those processes that increase storage strength or retrieval strength that are most desirable for learning. However, we would extend this argument to include more and different cognitive processes that are desirable for motor learning. For instance, in randomly-ordered practice, the learner is engaging different action selection processes across trials. In blocked practice, a learner can simply reinstate a cached version of a motor skill from short-term memory. Further, these action selection processes are distinct from the sensory-related attentional processes elicited by having individuals estimate their errors in advance of feedback (Liu & Wrisberg, 1997). As such, although many desirable difficulties will be associated with increased cognitive effort, distinct cognitive processes must be identified in each case.

Focusing on Errors

The evaluation of errors is an important frontier for research on desirable difficulty. We know that errors are an important determinant of future behavior. Specifically, the difference between actual outcomes and predicted outcomes are important signals for behavior to change (Frömer et al., 2016b). When these prediction-errors are large, learners are likely to change their behavior and try something new (Lohse et al., 2020). When practice becomes more difficult, we expect more errors during practice, but we need to understand how frequent and how large errors can be, before they stop being beneficial for learning.

Errors have both informational and motivational components, with the latter not accounted for in current frameworks of challenge and difficulty. We likely want to keep errors from becoming too frequent to prevent cessation of practice and low perceived competence and to preferentially engage physiological processes related to consolidation of procedural memories on the basis of reward (or unexpected success) and in response to performance improvements (Lohse, Miller, Bacelar & Krigolson, 2019). Adjusting difficulty to titrate errors and successes requires careful consideration and, as yet, we do not know what relative frequency/magnitude of errors is optimal. Indeed, no one level of difficulty maybe optimal even in a single session and dynamically manipulating difficulty may be the best solution for both learning and motivation.

Conclusions

Desirable difficulties and the related concept of challenge points are some of the most influential ideas in the field of motor skill learning. Empirical data largely support the idea that thoughtful increases in difficulty during practice have beneficial effects. Further, the relative challenge of these difficulties is specific to the individual. As we have discussed, however, questions remain to be answered. We still need: a better understanding of how desirable difficulties for motor learning can be identified in advance; a more specific mapping between difficulty, effort, and the underlying cognitive processes in a given context; and a better understanding of both the informational and motivational value of errors over time. These considerations will help us build on past work to develop a more mechanistic understanding of practice difficulty and make effective prescriptions for practitioners in movement related fields.

As a working hypothesis, we suggest that four conditions must be satisfied for difficulties to be desirable. First, difficulties are relevant to the practised and tested tasks (i.e., not distracting, purposefully fatiguing or task-irrelevant). Second, the challenge created by the difficulty depends on the individual's current experience, so we should seek to engage non-redundant cognitive processes. Third, desirable difficulties should result in steady improvements during practice, such that success is always achievable, but not guaranteed. Finally, we argue that difficulties are desirable when performance meets or exceeds the learner's expectations, but within the constraints of the third condition above. That is, overall performance may be low when difficulty is high, but learners should have an expectation of lower performance and continue to improve during practice. This last condition is based on both informational and motivational features associated with error feedback, which likely impact learning through different pathways.

Author Contributions

Nicola J Hodges and Keith R Lohse co-wrote this paper and made equal contributions to the conceptual content.

References

Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied*, *8*(1), 6-16.

Bjork, R. A. (1994). Memory and metamemory considerations in the training of human beings. In J. Metcalfe & A.P. Shimamura (Eds). *Metacognition: Knowing about knowing, 185-206*. Cambridge, Mass: MIT Press

Bjork, R. A. (1998). Intentional forgetting in perspective: Comments, conjectures, and some directed remembering. In J.M. Golding & C.M. MacLeod (Eds). *Intentional forgetting: Interdisciplinary approaches*, 453-481. Mahwah, N.J.: L. Erlbaum Associates

Bjork, E. L., & Bjork, R. A. (2011). Making things hard on yourself, but in a good way: Creating desirable difficulties to enhance learning. In M. A. E., Gernsbacher, R.W. Pew, L.M. Hough, & J.R. Pomerantz (2011). *Psychology and the real world: Essays illustrating fundamental contributions to society, pp 59-68*. Worth Publishers.

Ehrlenspiel, F. (2001). Paralysis by analysis? A functional framework for the effects of attentional focus on the control of motor skills. *European Journal of Sport Science*, *1*(5), 1-11.

Fischer, S., & Born, J. (2009). Anticipated reward enhances offline learning during sleep. *Journal of Experimental Psychology: Learning, Memory & Cognition, 35(6)*, 1586-1593.

Frömer, R., Stürmer, B., & Sommer, W. (2016a). (Don't) Mind the effort: Effects of contextual interference on ERP indicators of motor preparation. *Psychophysiology*, *53*(10), 1577-1586.

Frömer, R., Stürmer, B., & Sommer, W. (2016b). The better, the bigger: the effect of graded positive performance feedback on the reward positivity. *Biological Psychology*, *114*, 61-68.

Fuhrmeister, P., & Myers, E. B. (2020). Desirable and undesirable difficulties: Influences of variability, training schedule, and aptitude on nonnative phonetic learning. *Attention, Perception, & Psychophysics, 82*, 2049–2065.

Grieve, G., Karlinsky, A., Gopalakrishnan, S & Hodges, N.J. (June 2020). Moderating effects of a partner on the learning of different timing tasks. *Journal of Sport & Exercise Psychology, 42*, SXX (NASPSPA, Vancouver).

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.

Kang, S. H., McDaniel, M. A., & Pashler, H. (2011). Effects of testing on learning of functions. *Psychonomic Bulletin & Review*, *18(5)*, 998-1005.

Kantak, S. S., & Winstein, C. J. (2012). Learning–performance distinction and memory processes for motor skills: A focused review and perspective. *Behavioural Brain Research*, *228*(1), 219-231.

Karlinsky, A., & Hodges, N. J. (2018). 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. (2019). Manipulations to practice organization of golf putting skills through interleaved matched or mismatched practice with a partner. *Human Movement Science*, *66*, 231-240.

Karlinsky, A., Alexander, B., & Hodges, N.J. (2020). "You're wrong, I'll switch, I'm wrong, I'll stay": How task-switching strategies are modulated by a partner in a multi-task learning protocol. Submitted.

Keetch, K. M., & Lee, T. D. (2007). The effect of self-regulated and experimenter-imposed practice schedules on motor learning for tasks of varying difficulty. *Research Quarterly for Exercise & Sport*, *78*(5), 476-486.

Lam, W. K., Maxwell, J. P., & Masters, R. (2009). Analogy learning and the performance of motor skills under pressure. *Journal of Sport and Exercise Psychology*, *31*(3), 337-357.

Lee, T. D., Swinnen, S. P., & Serrien, D. J. (1994). Cognitive effort and motor learning. *Quest*, *46*(3), 328-344.

Lee, T. D., & Wishart, L. R. (2005). Motor learning conundrums (and possible solutions). Quest, 57(1), 67-78.

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 and Sport*, *68*(1), 100-105.

Liu, J., & Wrisberg, C. A. (1997). The effect of knowledge of results delay and the subjective estimation of movement form on the acquisition and retention of a motor skill. *Research Quarterly for Exercise and Sport, 68(2)*, 145-151.

Lohse, K. R., Miller, M. W., Bacelar, M., & Krigolson, O. (2019). Errors, rewards, and reinforcement in motor skill learning. In N.J. Hodges & A.M. Williams (Eds), *Skill Acquisition in Sport: Research, Theory & Practice, 3rd edition* (pp 39-60). Routledge: London.

Lohse, K. R., Miller, M. W., Daou, M., Valerius, W., & Jones, M. (2020). Dissociating the contributions of reward-prediction errors to trial-level adaptation and long-term learning. *Biological Psychology*, *149*, 107775.

Ma, Q., Pei, G., & Meng, L. (2017). Inverted u-shaped curvilinear relationship between challenge and one's intrinsic motivation: Evidence from event-related potentials. *Frontiers in Neuroscience*, *11*, 131.

Masters, R.S.W., van Duijn, T. & Uiga, L. (2019). Advances in implicit motor learning. In N.J. Hodges & A.M. Williams (Eds), *Skill Acquisition in Sport: Research, Theory & Practice, 3rd ed* (pp. 77-96). London: Routledge.

McDaniel, M. A., & Butler, A. C. (2011). A contextual framework for understanding when difficulties are desirable. In A.S. Benjamin (Ed.), *Successful remembering and successful forgetting: A festschrift in honor of Robert A. Bjork*, 175-198. NY: Psychology Press

Ong, N. T., Hawke, J., & Hodges, N. J. (2019). Target Size Manipulations Affect Error-Processing Duration and Success Perceptions but not Behavioural Indices of Learning. *Brain sciences*, *9*(5), 119.

Ong, N. T., Lohse, K. R., & Hodges, N. J. (2015). Manipulating target size influences perceptions of success when learning a dart-throwing skill but does not impact retention. *Frontiers in Psychology*, *6*, 1378.

Palmer, K., Chiviacowsky, S., & Wulf, G. (2016). Enhanced expectancies facilitate golf putting. *Psychology of Sport and Exercise*, *22*, 229-232.

Poldrack, R. A. (2015). Is "efficiency" a useful concept in cognitive neuroscience? *Developmental Cognitive Neuroscience*, *11*, 12-17.

Poolton, J. M., Masters, R. S. W., & Maxwell, J. P. (2005). The relationship between initial errorless learning conditions and subsequent performance. *Human Movement Science*, *24*(3), 362-378.

Porter, C., Greenwood, D., Panchuk, D., & Pepping, G. J. (2020). Learner-adapted practice promotes skill transfer in unskilled adults learning the basketball set shot. *European Journal of Sport Science*, *20*(1), 61-71.

Rendell, M. A., Masters, R. S., Farrow, D., & Morris, T. (2010). An implicit basis for the retention benefits of random practice. *Journal of Motor Behavior*, *43*(1), 1-13.

Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: a review and critical reappraisal. *Psychological Bulletin*, *95*(3), 355-386.

Schmidt, R. A., Lee, T. D. (2019). *Motor Learning and Performance: From Principles to Application*. 6th Edition. Human Kinetics Press.

Shea, J. B., & Morgan, R. L. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning and Memory*, *5*(2), 179-187.

Simon, D. A., & Bjork, R. A. (2001). Metacognition in motor learning. *Journal of Experimental Psychology: Learning, Memory, and 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.

Wadden, K. P., Hodges, N. J., De Asis, K. L., Neva, J. L., & Boyd, L. A. (2019). Individualized challenge point practice as a method to aid motor sequence learning. *Journal of Motor Behavior*, *51*(5), 467-485.

Wright, D. L., & Kim, T. (2019). Contextual interference: New Findings, Insights, and Implications for Skill Acquisition. In N.J. Hodges & A.M. Williams (Eds), *Skill Acquisition in Sport: Research, Theory & Practice, 3rd ed* (pp. 99-118). London: Routledge.

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review*, *23*(5), 1382-1414.

Wulf, G., & Schmidt, R. A. (1988). Variability in practice: Facilitation in retention and transfer through schema formation or context effects? *Journal of Motor Behavior*, *20*(2), 133-149.

Zhu, F. F., Poolton, J. M., Wilson, M. R., Hu, Y., Maxwell, J. P., & Masters, R. S. (2011). Implicit motor learning promotes neural efficiency during laparoscopy. *Surgical endoscopy*, *25*(9), 2950.

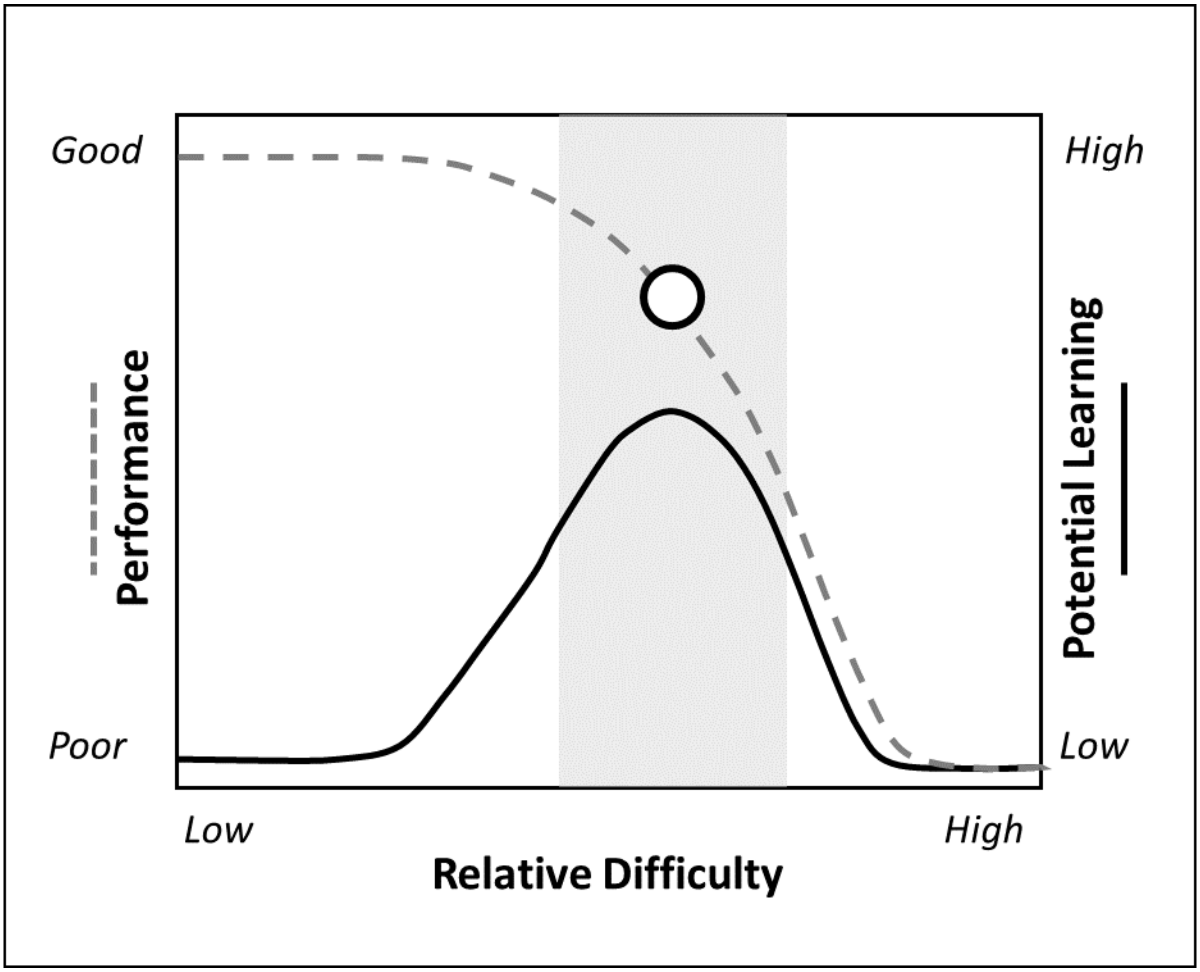

Figure 1. A conceptual model of the challenge point framework adapted from Guadagnoli and Lee (2004). The hypothetical optimal challenge point is shown as a white dot. However, because we lack empirical data to support the precise placement of this point, we highlight a challenge "zone" in light grey. Note then when difficulty is moderate, there is a decline in performance that intersects with a (hypothetical) point of maximum potential for learning.

Figure 2

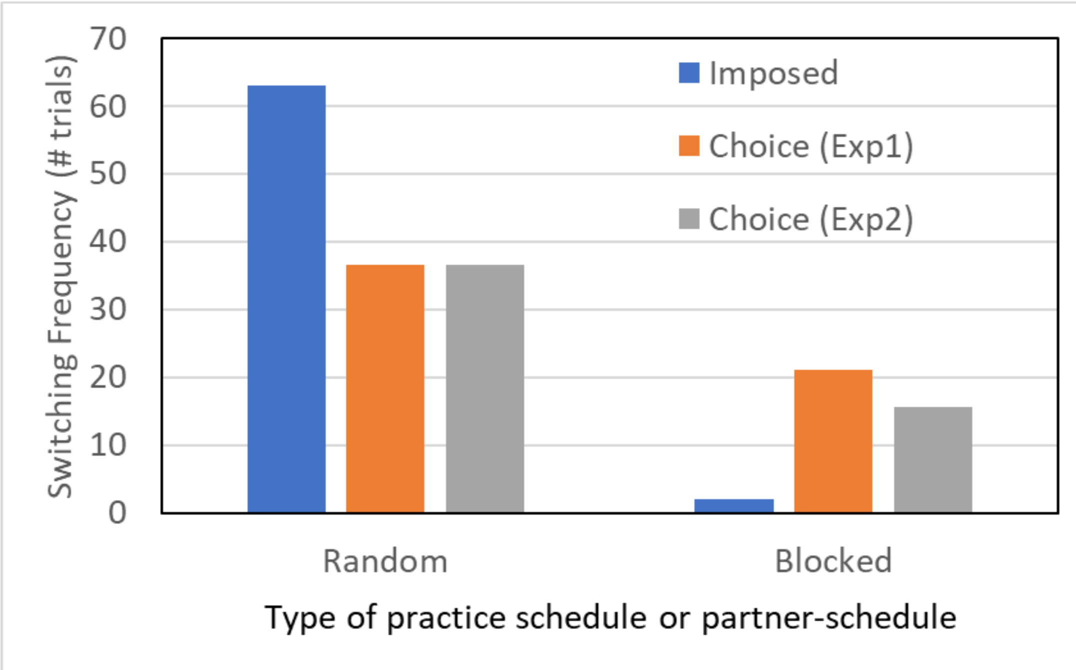

Figure 2: Number of trials where switching to a new sequence occurred for individuals practising with a partner who either had an imposed random-order or blocked-order schedule or were allowed to choose their schedule when paired with a random-order or blocked-order partner. Note that the amount of switching for the imposed schedule partners remained the same across two experiments (Experiment 1 refers to Karlinsky & Hodges, 2018 and Experiment 2 refers to Karlinsky, Alexander & Hodges, in review).