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Developing Motor Skill in Practice: A Case of Mastering 'Heelflips'

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Abstract

We present the case of JB who is a highly motivated, amateur skateboarder and our online interactions with JB over the course of a year. These interactions concerned a discussion of motor learning practice principles that would potentially help JB acquire difficult and risky motor skills involved in skateboarding tricks. We focused our discussions and eventual recommendations on the skill of heelflips and the initial stage of skill acquisition. Acquiring a new skill requires a rather nuanced appreciation and application of the motor learning literature, as a significant body of research is based on motor skill refinement. We offered advice with respect to demonstrations and feedback, practice organisation and task complexity and challenge. JB acquired the skill which was causing him difficulty, which we hope was in part a result of our consultations. He provides some reflections about his practice and we frame our discussions with respect to motor control and learning theory and concepts related to effective error-detection and correction.

Keywords: Motor learning, Skill Acquisition, Instructions, Movement Pedagogy, Coaching

Introductory Picture – Skateboarder doing a heelflip? Maybe early in the movement with the board just getting off the ground?

Learning Outcomes: After reading this chapter, we expect the reader will:

- Have a more mechanistic understanding of the perceptual, cognitive, and motor demands that are required in learning a complex skill.
- Be able to explain how different practice and instructional methods can facilitate learning for people of varying skills, who are practising skills of varying difficulty.
- To develop an awareness of motor learning principles that guide best practice with respect to challenge and constraints.

Things to think about:

- Motor skill learning is a complex proposition, with constraints from the learner, the task, and the environment. How can we modify these constraints to optimize learning?
- Our best models of learning (e.g., computational, psychological, physiological) come from reductive, controlled experiments. In contrast, most learning occurs in more complex skills in more complex environments. We argue that the generalization from the laboratory to "the street" is good, but what do you think?
- Faced with performers of different abilities, where one person wants to refine an existing skill (i.e., perform it more accurately and consistently) and one wants to acquire the skill (i.e., learn how to do it), how might your recommendations about how to practice differ across the two individuals?

Introduction to the client & issue(s)

We present the case of an amateur skateboarder, JB, who wanted to significantly improve his skateboarding skills and was prepared to dedicate high amounts of practice to achieve this aim. This case was appealing to us in the Motor Skills Laboratory at the University of British Columbia, because the acquisition of novel, complex and potentially risky skills defines many sporting situations (e.g., skating, diving, snowboarding, gymnastics). Despite its applicability, the initial acquisition stage, when a performer is learning to successfully and repeatedly perform a new, complex skill, has received relatively little empirical attention in the motor learning literature As should become increasingly apparent in reading this chapter, this process was a dynamic and dyadic process that involved learning on both our parts. Whilst there are certain known principles that appear to guide motor skill acquisition, rarely are these principles studied interactively in laboratory work (where the goal is mostly one of isolating specific variables and effects to make conclusions about causes). Moving from the laboratory to the field presents unique challenges, and as became clear to us as we embarked on this challenge, our role was mostly one of offering JB new ways to approach thinking about problems and solutions and help in framing the understanding of why current methods appear (or not) to work.

JB was a 29-year-old amateur skateboarder, living in Washington DC when this consultation began, but who is now living the skateboarding dream in Venice, California. A decade ago, he skated regularly, spending an estimated 3-5 hrs per day, 5 days per week, over the span of 4 years. While his time investment in practice was considerable, JB attested that his practice was not what is now defined as "deliberate practice" (Ericsson, Krampe & Tesch-Romer, 1993). That is, effortful practice, designed specifically to improve performance. Thus, 10 years later, JB was interested in returning to/surpassing his former level of skill by focusing on deliberate practice using motor learning principles. Taking a remarkably proactive and scientific approach to his training, JB contacted several motor learning researchers via email to solicit their feedback in designing his practice (prior to contacting our research group).

JB begun this new practice regime with a few ideas of how to interleave the order of the tricks he was practicing and began collecting some of his own data (the number of attempts, the number of successes) to track his progress. His first goal was to the relearn basic flip tricks that form the basis for other, progressively more complex tricks in skateboarding. Re-acquiring older skills was proceeding smoothly, but a major hurdle for JB occurred in trying to learn heelflips, shown in Figure 1. Heelflips are a type of flip trick in which force from the fore-foot/side of the foot rotates the board around its long axis in mid-air before landing. Although JB felt successful in relearning other flip tricks, such as kickflips, JB found heelflips especially difficult; performing approximately 100 attempts in a session, but only successfully landing 1-4 attempts. JB filmed himself, engaged in explicit error-analysis between attempts, and used visualisation as a strategy to overcome these failed attempts. Unfortunately, over the next few months, JB continued to struggle with heelflips, failing to land the trick despite his increase in deliberate practice.

-- Insert BOX 1 about here --

JB subsequently contacted the Motor Skills Laboratory for our input on his practice regimen and advice that we might have on how he could better structure his practice sessions (in April, 2013). JB's practice on heelflips provided an interesting and unique case study for motor learning research. In experimental studies of learning, researchers often ask participants to learn a skill by scaling or refining an existing action in a novel context (e.g., the simple action of a button press must be strung together in a novel pattern for sequence learning tasks; the simple action of a reach must be adapted to visual or dynamic distortions in adaptation learning). Although a number of authors have studied how practice variables affect the acquisition of more complex skills, such as balancing on a stabiliometer (e.g., McNevin, Shea & Wulf, 2000), learning to juggle (e.g., Anshel & Singer, 1980), or coordinate both arms under difficult timing constraints (e.g., Hodges & Franks, 2002), this initial stage of going from failure to success of an action, at least within the laboratory setting, has received relatively little attention. In JB's case, he certainly had familiarity with other skateboarding tricks, but not heelflips specifically. Thus, although some knowledge from previous skills might positively transfer, learning heelflips was largely learning "from scratch".

Learning a truly novel skill poses a lot of interesting theoretical questions. Certainly it is difficult to fathom how the motor system can correct errors in truly novel movements when there is no reference (even an approximate reference) for what the correct movement should be. Furthermore, although the amount of practice is one of the best predictors of success/competency in a skill, there is tremendous variability in the amount of practice needed to attain a certain skill level and a myriad of variables that can enhance or hinder learning on any given attempt (Schmidt & Lee, 2011). Initial acquisition of a skill is not defined by a monotonic, linear relationship between practice and performance (e.g., Newell et al., 2001; Dickinson et al., 2004), such that practice is only beneficial once an individual gets close to the target skill. In JB's case, considerations about learning must also be balanced against considerations for safety and injury prevention. Although the risk of injury is not a common theme in motor learning research, safety is an important consideration when learning many complex and dynamic skills in both sport (e.g., for gymnasts, free-runners or snowboarders) and occupational settings (e.g., for firefighters, military personnel or police).

Our aim in this chapter is to present evidence-based practice pertaining to motor skill learning and principles of practice based on how to structure practice, how to instruct and what and when to watch and receive feedback. Skill acquisition specialists need to be familiar with aspects of practice that pertain to a variety of skills, a variety of skill levels and that have generality across a range of sports. We try to address key motor learning concepts in this chapter, but more comprehensive reviews can be found in the suggested readings at the end of the chapter.

Initial needs assessment

Despite investing considerable time in researching how to structure his practice, JB was struggling to learn how to heelflip. JB’s errors varied from attempt to attempt and day to day, but ultimately he was not consistent (and often not even successful) in landing the heelflip. He reported that often he could fix a problem on one day to have a new problem arise the next. We discussed his current practice schedule to see if we could offer advice on motor learning principles that he could incorporate into his practice sessions. In a series of email exchanges, we identified a few key areas of discussion that could be informed by empirical research on motor learning:

- Deliberate practice and amount of practice (e.g., the number of tricks to practice in a session).
- Practice scheduling: the order in which tricks were being practiced (e.g., practising complex tricks at the beginning of a session to avoid fatigue).

- Part-whole practice/natural skill progressions (i.e., how best to break skills down into simpler components).
- Demonstrations and feedback (i.e., how and when to supplement physical practice with observational practice).
- Attentional Focus (i.e., where best to direct attention during performance attempts).
- Pressure/anxiety and safety (i.e., potential ways of decreasing fear and anxiety during performance/practice).

After JB told us about his current practices over email and some relatively broad comments were made in response, members of the Motor Skills Laboratory met to discuss this problem as a group and suggest evidence-based interventions that could help JB learn heelflips (and potentially other tricks). Before our intervention, JB had roughly designed his practice session to complete approximately 100 heelflip attempts in each session. Beyond simply making these attempts, having read about the value of deliberate practice, JB would attempt three, reflect on any mistakes, visualise a solution to that mistake and then attempt to implement the solution on the next three attempts. He even reported filming himself and then looking at the footage frame-by-frame to identify errors in his movement. JB reported that this strategy was mildly successful as it would help him fix a particular mistake in subsequent attempts. However, if he managed to fix one mistake another problem would emerge.

JB also reported that he was attempting to break the skill down into component parts (e.g., squatting over the board to make sure his weight distribution was correct, jumping without a board flip) and practicing those skills in isolation. JB reported practice for several days with this method. Over the course of six practice days, JB landed zero of an estimated 500 full heelflip attempts using these methods.

Following several more weeks of practice (and about 700 attempts), JB was still struggling to land heelflips (approximately 10 successful landings in 700 attempts). In correspondence, he suggested that, "maybe it's just an irrational fear of falling" that was specific to that trick. The anxiety appeared to be specific to heelflips as JB was able to land other similar tricks (e.g., a kickflip) and performed other tricks that had a high risk of injury (e.g., jumping stairs, grinding hand rails, dropping in on steep ramps).

Framework and intervention for delivery

We created a list of motor learning principles that we thought would be relevant for JB. These principles were related to the topics outlined in the previous section but more specifically concerned 3 major themes: effective feedback and providing relevant and useable demonstrations, scheduling practice to best promote learning (and avoiding fatigue/boredom), and creating optimal task difficulty. These 3 themes seemed to capture the essence of the topics detailed above as well as being themes that have received considerable attention in motor learning research. Our theoretical framework was primarily one based on information-processing theory and cognitive-behavioural interventions, although we also considered how a constraints-based framework of practice would complement these potential interventions. We then wrote to JB with recommendations and ideas based on these practice principles and maintained a dialogue (over email) for how these practice principles might best be implemented. Each principle and JB's experience trying to employ it are discussed below.

Effective Feedback

Bringing in a Coach

There was general agreement in the laboratory that JB would benefit from having a knowledgeable skateboarder with him who could watch and evaluate his heelflip from different angles. Intuitively, the idea of having an expert partner/coach to facilitate learning is appealing, but this practice is also grounded in motor learning research. Motor learning, after all, is a highly complex process in which a redundant system with many degrees of freedom (joints, limbs and muscles) must be controlled in order to generate very precise movements in the environment (e.g., Guigon, Baraduc, & Desmurget, 2007). Furthermore, feedback from the environment seldom makes it clear what corrections need to be implemented in the motor system. This disconnect between errors (detected through sensory feedback) and which aspect/s of motor control need to be changed is referred to as the 'credit assignment' problem (Wolpert, Diedrichsen, & Flanagan, 2011). Accurate credit assignment is probably the greatest help that a coach can provide. An expert who has an understanding of the mechanics of the action, experience performing and watching successful and unsuccessful attempts, and (critically) experience in successful interventions, can help an athlete identify what is going wrong in a movement that is ultimately affecting the outcome. Error-detection, credit assignment, and error-correction can happen endogenously (i.e., internally generated processes, outside of conscious control) as illustrated by the white boxes in Box 2. However, externalising some of these processes, by bringing in an expert partner/coach can expedite the learning process (we illustrate in Box 3 at what stages of execution certain coaching methods might best enhance these more endogenous processes, but we provide more detail pertaining to these two figures in subsequent sections).

-- Insert Box 2 and 3 about here --

The suggestion to bring in a coach might seem too self-evident to be useful, but JB's response surprised us. Although he agreed that effective feedback was a critical element of deliberate practice, JB said that skateboarding, in general, resisted the idea of coaches. In skateboarding, the culture appears to prefer autonomous skill development and discovery learning (consistent with a larger rejection of organisation and authority in the sport, Beal & Weidman, 2003, although there is evidence that this might be changing with certain cities publicly offering coaching clinics for adults). While codified skill progressions and drills might not be part of skater culture, observation and feedback do often come from peers when skaters skate together. In JB's case, however, he was skating after work on his own (the only skater in his current peer group), making it difficult to find a partner to train with. However, JB did have access to numerous online videos that showed successful and unsuccessful heelflips performed by both expert and novice skateboarders. JB also had the capability to record his own attempts. Thus, we tried to provide JB with principles for the effective use of video feedback (when watching his own attempts) and video demonstrations (when watching the attempts of others).

Video Feedback and Demonstrations

One of the difficulties in early skill learning is how to form a good approximation of what action is required (what some people have referred to as a ‘reference of correctness’ or ‘perceptual blueprint’), then in translating this reference into motor commands and hence successful execution (Adams, 1986; Sheffield, 1961; Schmidt, 1975; Willingham, 1998; Wolpert et al., 2011). We know that in early learning much of the information that is extracted from a demonstration is strategic in nature, mainly reflective of the positioning and timing of limbs (e.g., keep the knees bent, don’t rotate the head) and that feedback which helps to alert the learner to these strategic features is generally a good tool for learning (see Magill & Anderson, 2012; Hodges & Franks, 2008). JB mentioned that he was interested in watching "*youtube*" videos of others and filming himself for reflection and to get augmented feedback about things he might not be seeing (see website reference list below for some examples). There is evidence that coupling demonstrations with self-referenced video feedback aids the potential of both these instructional methods (e.g., Hodges, Chua & Franks, 2003).

Beyond a strategic role, the function of demonstrations in aiding learning has recently been debated. Although one might have a vague understanding of what is being done when watching someone perform a novel and relatively complex skill (such as heelflips, or an ice-skating or gymnastic stunt), arguably this level of understanding is quite vague. This is of course one of the major problems facing new learners, how to understand what is being done such that the demonstration can be transformed to the appropriate movements. We now know that a person's motor capabilities inform their understanding (and arguably this transformation); such that when you cannot perform an action, then in some ways, you cannot perceive it appropriately either (e.g., Calvo-Merino et al., 2005, 2006). In this regard, the informativeness of demonstrations should be viewed as dynamic, changing as the skills of the learner change, but also limited prescriptively with respect to early skill learning. In a recent 2-ball juggling study, although observers thought they were learning from repeated demonstrations, these capability judgments were overly optimistic compared to actual success after watching (Hodges & Coppola, 2014).

Somewhat contrary to the statement above regarding overly optimistic perceptions of competence following successful demonstrations, when performers are allowed to physically practice, there is evidence that they are quite good judges of when feedback or a demonstration is needed. In research on self-scheduling of feedback and demonstrations, people have tended to request feedback and demonstrations on a relatively small percentage of trials (approximately 10%, e.g., Wulf, Raupach & Pfeiffer, 2005, although this increases to about 20% for more skilled individuals; Hodges, Edwards, Luttin & Bowcock, 2011). This relatively low frequency of presentation is often shown, however, to be as effective as giving feedback or demonstrations more frequently (but as prescribed by the 'teacher'). Interspersing physical practice attempts with observation of others (or of oneself) also seems to be a good practice technique (see Ong & Hodges, 2012 and Hodges & Ste-Marie, 2013 for reviews). Watching demonstrations early in practice, rather than later, seems to be best, at least for acquisition of relatively simple skills (Weeks & Anderson, 2000). Of course, some idea of what the goal of the action is is needed for learning to occur, yet how demonstration might work to best convey this goal is rather murky. Combining different types of models, particularly learning or novice models with more skilled models has been shown to be a good method (e.g., Rohbanfard & Proteau, 2011). In this way, the learner gets to see what is "correct" or a potential solution, as well as engage in the problem solving process of other learners and potentially learning what is not working. Seeing errors in others' performance might help make errors in one's own performance more salient.

To best optimise long term learning, it appears that showing a demonstration after a performance attempt might be better than prescribing what to do before each attempt (e.g., Richardson & Lee, 1999). That is, try achieving the desired performance goal (e.g., flipping the skateboard in the air using the foot and landing), before seeing how it should (or could) be done. Although this may be a more effortful way of learning (i.e., thinking about what to do and trying one's own solution before being told what to do), there is considerable evidence in the learning research that this type of practice is good for memory retention of the skill. In some ways, the demonstration then acts as feedback, rather than merely something to passively copy.

Scheduling of Practice: Integrating Old and New Techniques

Reflecting on JB's practice schedule, we presented some advice on how to organise practice more effectively. Specifically, we recommended integrating more repetitions of successful tricks and, when practicing heelflips or other new tricks, breaking attempts into *practice* trials and *test* trials. The intention in practice trials would be to de-emphasize success as a goal, instead focusing on exploration and experimentation with the technique. Conversely, on test trials, success would be the goal and we encouraged JB to adopt an external focus of attention on the movement of the board (see Wulf, 2007). That is, in these test trials, we encouraged JB to focus more attention on successfully landing the flip and what the board had to do, rather than his technique and his body movements (with the latter being defined as an internal focus). JB took these recommendations, developed a practice schedule roughly like the one below and recorded observations about the effectiveness of this method:

1. Warm-up
2. Learning/Acquisition Phase (practicing new tricks).
    a. 5 practice trials for new Trick A.
    b. 1 test trial for new Trick A.
    c. 5 practice trials for new Trick B.
    d. 1 test trial for new trick B.
    e. Repeat as desired...
3. Refining/Diagnostic Phase (practicing ‘successful’ tricks, that is tricks with a relatively high success rate).
    a. Approximately 10 attempts at each known trick, randomly interleaved practice of different tricks.

b. Occasionally increasing trick difficulty (e.g., clearing obstacles, etc.)

During the learning phase, new tricks were repeated in combinations of blocked (i.e., repetitive) practice trials followed by test trials, until JB was gaining success in landing that trick. Once some success was obtained (e.g., landing a trick more consistently), then we recommended that a new trick (e.g., Trick C) could be added to the rotation. In practice trials, the emphasis was on attempting the trick, or parts of the trick, with less focus on the success of the trick and more focus on exploring the movement. Test trials, conversely, put the emphasis on successfully landing the trick, allowing JB some feedback as to how close he was getting to correctly performing the trick. In the test trials, JB was encouraged to focus externally on the skateboard and/or on the desired landing spot (see Wulf, 2007). There is a significant body of research showing that attending to the effects of the action on the environment (rather than the movement and its mechanics), allows for a smoother and more automatic mode of control, better performance and potentially better skill retention (e.g., Lohse, Wulf, & Lewthwaite, 2012). During the refining phase, old tricks would be practiced in a more random /interleaved fashion with added difficulty (as scheduled by JB on that day).

Practice was structured in this way for a number of reasons. First, we felt that the volume of practice for JB's previous sessions was quite high. JB also practiced heelflips (his most challenging skill) later in the practice session, when fatigue (either physical or mental) would potentially hinder success. Thus, we suggested that JB move the acquisition of new skills to earlier in practice following his warm-up (advice that JB found really useful). Although previous research in simple laboratory tasks suggests that fatigue negatively affects performance more than it affects learning (Alderman, 1965; Carron, 1969; Schmidt, 1969), we reasoned that the intensity and complexity of the trick might make it a skill more constrained by fatigue[1].

Second, in view of research on contextual interference (see Box 4 for a description of this effect and references) and its dependency on the demands of the skill for the performer (e.g., Guadagnoli, Holcomb & Weber, 1999; Porter & Magill, 2010), we thought that JB's previous practice schedule had too much interleaving of heelflips with other skills. In general, schedules of practice that are high in CI (i.e., random or interleaved practice of different skills), lead to better long-term retention than schedules of practice that are low in CI (i.e., repetitive, blocked practice of one skill before moving onto practice of the next). This is despite the fact that performance improvements seem to be more pronounced, at least within practice, with the low CI, blocked schedule. Although there is considerable evidence that long-term learning is aided by bringing interference into practice, this type of practice is most beneficial when the learner has some experience successfully performing these skills. With less experience, or higher complexity of skill, progressing from a more blocked to random type of practice within or across practice schedules is arguably a better technique (see Guadagnoli & Lee, 2004 for rationale).

-- Insert Box 4 about here --

Thus, even though JB might attempt 100 heelflips within a session, these attempts occurred in the larger context of practice, such that they were interleaved in a relatively random fashion throughout the practice session. Thus, to reduce the contextual interference between

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[1] The tasks used in previous laboratory experiments on fatigue and motor learning were continuous tasks in which participants were still, arguably, successful but more errorful under fatigue. That is, in a pursuit rotor task, participants showed larger errors post-fatigue, but were still able to track the target. In the heel-flip, however, JB was not simply showing movement errors in an otherwise successful attempt; JBs attempts were failing. Thus, we thought that if we could improve JB's performance by reducing fatigue, increasing the likelihood of a successful trial, this might be beneficial to learning as well. The difference between errors and failures as well as the influence of fatigue on learning skills that require powerful movements are, to our knowledge, not well studied.

trials, we suggested the balance of 5 practice trials and 1 test trial for each skill, with no more than two new skills practiced within a session. This makes the practice more blocked in nature, decreasing the challenge associated with moving between numerous skills from trial to trial and allowing JB time to cognitively process errors and make changes to the same skill across practice attempts.

Third, in addition to moving the older skills to the end of the practice session, JB was encouraged to occasionally add challenges to these successful tricks in order to keep their functional difficulty high. The goal of encouraging JB to add degrees of difficulty (or interference) to these already successful tricks was to allow learning/refining of these skills to continue (see Guadagnoli & Lee, 2004). Progressive increases in task relevant difficulty (or challenge) have been shown to be beneficial for experimental studies of learning in the laboratory and in applied physical therapy sessions (e.g., Pollock, Boyd, Hunt, & Garland, 2014). JB commented that practicing skills in an environment that required the clearing of obstacles, or following lines, although adding difficulty, positively aided his attentional focus. Focusing on clearing a beverage bottle (what he referred to as ‘open’ conditions, and what is referred to in the literature as an external focus) appeared to help the fluidity of his movements, whereby “my eyes have to shift away from the board and onto the obstacle, such that the throw is more or less running on instinct”. JB also noted that the type of practice schedule we had devised resembled similar recommendations by the skateboarder (and cartoonist) Christopher Chann (see website references). We reasoned that it was encouraging that someone from “inside” the skateboarding community (an expert skateboarder, yet a novice motor learning theorist) had made similar recommendations to us (non-skateboarders, yet motor learning experts)!

Optimal Difficulty: Simplifying a Complex Skill

JB had questions about reducing the difficulty of the skill by decomposing the heelflip into constituent elements. We cautioned against this, however, as part-skill practice is often less effective than whole-skill practice when the stages of the skill depend on each other (for a review see Lee, Chamberlin & Hodges, 2001). With independent stages, it can be appropriate to break a skill down into constituent elements and practice these stages individually. In the heelflip, however, timing and balance at each stage are dependent on the step before. Thus, we advised JB not to simplify the skill by removing critical elements of the trick, but to use assistive devices or environmental constraints to help simplify the skill, yet at the same time, keeping the skill (and balance constraints) relatively intact (such as practicing on a softer surface or without wheels; see Davids et al., 2010). In this case, JB started holding onto a handrail while attempting the trick.

Using the handrail to give JB additional control in the air (and alleviate fears associated with landing "primo" – when the board lands on its side causing pain to the arch of the foot) helped considerably. He reported that he was able to land about 20% of his attempts while holding onto the handrail (although he was cognizant of the fact that he would use the rail to aid his jump height, such that forcing himself to only put one hand on the rail would prevent this temptation). He also noted that interleaving assisted trials with unassisted trials improved the unassisted trials. Although he was still not landing heelflips in the unassisted trials, JB reported that his form and the motion of the board were improved (i.e., more elevation of the board and the board spinning closer to his feet).

Increased success while using an assistive device (e.g., the hand rail) is promising, but research on assistive technologies in motor learning has shown that transfer from assisted to unassisted situations is not always substantial (for a recent review of the physical guidance literature see Hodges & Campagnaro, 2012). Furthermore, continued training with an assistive device may lead to dependence on the device, because a learner fails to develop internal error-detection and correction mechanisms when training with physical guidance (Winstein, Pohl & Lewthwaite, 1994). Thus, major concerns when incorporating assistive devices into training are the amount of physical guidance that the device provides and the regularity with which the device is used. Experimental data suggest that progressively fading out the use of an assistive technology is beneficial because early use of the device facilitates learners' performance early, but reducing the use of the device over time allows learners' to develop their own error-detection and correction mechanisms that they can rely on when the device is no longer being used. In JB's case, he limited himself to only using one hand on the rail, rather than both, to prevent this dependence and extra height boost that both hands on the rail gave him. Sports with a high risk of physical injury, such as gymnastics, have taken advantage of this principle for many years, using manual guidance early in practice to reduce the risk of harm while giving learners' physical guidance through the movement (Arkaev & Suchilin, 2004). The principles underlying constraints-based methods of instructions are also based on the premise that physical constraints can help bring about desirable movements. For example, using a soft bar to jump over might help the performer concentrate on height and the lift of the board, rather than the mechanics of the flip. Defining a narrow space for landing the board might also help to bring about a more effective (tight) technique, merely through a focus on landing within a boundary. This also has the advantage of keeping attention focused on an external outcome effect, rather than on the mechanics of the movement.

In a skill with a high risk of injury like skateboarding, the learner's level of arousal is understandably high. Heightened arousal from somatic threat can greatly reduce the efficacy and efficiency of motor behaviours, generally making movements slower (Pijpers, Oudejans, & Bakker, 2005), and can also change gaze behaviour (Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008), altering the availability and quality of perceptual information to the motor system. These changes to both action execution and perception clearly have the potential to interfere with learning. As such, dangerous skills might be a particular case where assistive devices not only improve the learner's safety during training, but also facilitate learning specifically because they ameliorate some of the negative effects of arousal on the perceptual-motor system (see also Heinen, Pizzera & Cottyn, 2009 who showed that assistive guidance led to a reduced fear of injury for certain gymnastic skills). That is, assistive devices need to allow a learner to perform an approximate movement for learning to occur, but beyond repetition of the appropriate movement, the reduced anxiety experienced during training can also positively impact learning.

Self-reflection

Working with the revised schedule of practice, where we recommended practicing difficult skills at the beginning of practice, a mix of practice trials and test trials for heelflips, progressively fading out the use of assistive devices (in this case, a hand rail), and the use of video demonstrations and feedback to aid in detection and correction of errors, JB started landing heelflips in ~4 weeks of continued practice. By JBs count, he was landing heelflips 40-60% of the time following the intervention (compared to about 1-2% before the intervention). As this was a case study, it is not possible to establish if the evidence-based prescriptions in our intervention caused JB to improve, but it is reassuring that he did!

As research continues in motor control, motor learning, neurophysiology, and experimental psychology, we are also seeing a growing role for skill acquisition specialists in applied settings (see Button & Farrow, 2012; Williams, Ford, Causer, Logan, & Murray, 2012; Farrow et al., 2008). Connecting laboratory and field-based research can be challenging, as in the laboratory, reductionist approaches are used to mechanistically study the relationships between a limited number of variables, whereas in applied settings, complex interactions between personal, environmental, and task constraints make it difficult to tell what part/s of an intervention are having an effect and why. This knowledge translation is not insurmountable, however, and in Boxes 2 and 3 we present schematics that connect the motor learning principles applied in this intervention to computational models of motor control and learning (see Wolpert et al., 2011).

As articulated by Willingham (1998) and Hollerback (1982), the problem of motor control can be thought of as the transformations that occur between the formulation of a movement goal and the muscle activations that result in movement. Motor learning can then be framed as the problem of tuning these transformations to create relatively permanent changes in the capability for behaviour. As shown in Box 2, high-level 'goals' (e.g., "ollie", meaning get the board off the ground with the feet still planted) are transformed into 'motor plans' (e.g., the sequence of sub-movements required to ollie) which are transformed into 'execution' of the movement (e.g., activation of particular muscles involved in the ollie) resulting in physical movement of the body and the skateboard which are perceived through sensory receptors. What is important from a learning and instructional standpoint is how the error signals that are generated during movement can be refined and decreased with practice. Shown in Box 2 (white boxes), these error signals can occur endogenously, outside of awareness. These error signals have been described in detail elsewhere, but here we list them as Signal α and Signal β. Signal α is a result of the comparison between the desired end-state of a movement to the actual end-state of the movement. This signal will have a magnitude (e.g., very wrong, less wrong, mostly correct, correct) but it can also have a direction (e.g., moved too far/short, joint angle was too obtuse/acute, etc.). Signal β is due to a comparison of the predicted state (formulated after the motor plan has been sent) to the actual state. This signal will similarly have a magnitude and a direction, but it represents whether a movement did what the motor system "thought" it would do based on the plan that was sent and executed.

As an explanatory example, if I am borrowing my friend's skateboard it is going to be different from my own and, as such, slightly different motor commands will be required to accurately control it. If my friend’s skateboard is heavier than mine, more force will be required to ollie. On my first attempt, I apply my typical motor commands for an ollie and the board barely leaves the ground. Signals α and β are generated. Signal α generally suggests that something wrong happened during execution. Signal β clarifies what went wrong by suggesting that our predicted outcome (the usual large jump we get when we ollie) did not match the actual outcome (the shallow ollie we just did). This information can be used to modulate the appropriate level of force on the next attempt. This is just one example of how α and β error signals can be used to refine motor control processes during learning. In Table 1 we have illustrated how various degrees of error in either of these processes will implicate performance and ultimately learning. The key thing to consider is that error signals exist on a continuum from large to small. By combining error signals, we can reduce some uncertainty in what aspects of motor control need to be corrected, but even then, the appropriate correction is often far from clear based on this endogenous information alone.

In Box 3 we have shown how changes in the practice environment might augment or supplement endogenous information, leading to more reliable or more informative error signals. For instance, external feedback provided by a coach or via video feedback, might provide a better estimation of the actual state of the motor system (e.g., "your foot is not far enough forward on the board"). External feedback and instructions might make this error signal more interpretable and also improve how this error signal is used through better credit assignment. That is, a coach can help you detect that your balance is shifted too far backward, but also can help you pinpoint when and where this error starts to occur in the movement.

Similarly, video demonstrations by experts or even by novices, provide a ‘reference of correctness’ for how the movement (or stages of the movement) should or should not look. This can be conceptualized in the model as a more accurate estimate for the desired state of the system and a clearer “goal” focus. A more accurate representation of the desired state could alter motor planning and execution transformations in the 'down-stream' efferent pathway. A more accurate representation could also lead to a more informative error signal because a more valid desired state is being compared to the actual state of the system.

Assistive devices can provide safety during the execution of dangerous skills but can also help to reduce the complexity of the movement, reducing the number of transformations required during motor planning and making the next state of the system easier to predict. Gradually fading out the use of assistive devices allows the learner to improve the accuracy of some transformations, bringing the desired state closer to the actual state, before all of the relevant motor transformations need to be handled at once (when the assistive device is completely removed).

Finally, moving more complex skills to early in the practice session means that there is less neuromuscular fatigue during movement execution. Reduced fatigue could help ensure that the actual movement is more commensurate with the intended movement, bringing the actual state closer to the predicted state. Changing the number and order of skills being practiced affects these processes as well. By bringing in more interference between the practice of various skills as the skills become more successful, will ensure that the planning processes are improved from trial to trial, keeping cognitive effort between trials high, aiding long term retention.

Thus, in many ways, we felt that the intervention was successful, but there are number of things we would prefer to do differently, if we had full control of the situation. Although we were generally satisfied with being able to bring motor learning theory to the table to answer JBs questions and design an effective practice schedule in concert with him, it would have been far preferable to work with JB personally, rather than over email, and track his performance data with greater rigor. It might have also been helpful to get some feedback from other skateboarders about their experience learning these tricks, or indeed, from athletes in similar extreme or high-risk sports (such as snow-boarding or diving). We asked JB to give us some reflection on our motor learning feedback and his experiences with acquiring the heelflip and motor learning in general. We close with JB’s response.

“I think switching the sessions around so that the task to be acquired was early in the session was probably the most useful advice. This focus on a more difficult trick earlier in practice, particularly in a long session, did however come at the expense of accurate reflection in the diagnostic section, in that fatigue, carrying over from the previous sections, reduced performance. So, for example, I’d miss lots of backside 180’s and record these as misses, even though the faults were more related to fatigue rather than about me not knowing how to do the trick. For feedback, I agree that coaching is probably the best route for improvement, since it’s immediate and less time consuming than waiting until I get home, looking through videos, and getting feedback far removed from the actual practice session.

As far as external focus, I think I more or less focus on how tricks ought to "intuitively feel" rather than a strictly external focus (i.e. I want to flip this board in such a way) though I do use this external approach when initially "forming" a new trick. This "intuitive feel" is also what I tend to visualize when watching how to execute a new trick (i.e. I imagine how the side of the board feels against the base of my pinky toe). When freely skating, my eyes are usually looking ahead and I "recreate" the sensation of a trick, for example a 'pop shove it' (i.e., when you stay in relatively the same spot and the board does a 180° flip so you land on the other end of the board). Oddly enough, I was just reading research on language learning <http://time.com/3013439/language-trying-hurts-learning/> and I think this is also applicable here, though I probably differentiate between sensing how things ought to feel, and say a procedural "internal focus" (i.e. I need to move my foot to such a spot) which probably isn't as productive. I'm reminded of when I was learning how to drive a stick-shift/manual car and kept stalling. Someone took my hands and applied pressure on my left to mirror the clutch, and my right as the accelerator. I took those signals in that example and successfully applied that in the car I was driving.

What would be great is a machine that would apply the 'sensation' of a heelflip to a beginner's feet to provide a model. Perhaps a robotic device that could apply touch and pressure at the appropriate times. I have a feeling this would seriously reduce the time it takes to learn complex motor skills. I know for heelflips, I think what really might have helped is knowledge of the 'sensation' needed for this weird back lean/front foot snap, as this wasn't originally in my mental model of the sensation of a heelflip. I also find logging my practice hours and tricks time consuming and I think an activity monitor device, such as the one now manufactured by Kickstarter © called "Trace" would be useful in freeing my mental resources to just focus on the task at hand rather than data collection:

<https://www.kickstarter.com/projects/activereplay/trace-the-most-advanced-activity-monitor-for-action>.

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Further reading

- Davids, K., Savelsbergh, G. & Renshaw, I. (2010). *Motor Learning in Practice: A Constraints-Led Approach*. London/NY: Routledge. - A series of chapters on different sports where a constraints-based /ecological framework has been adopted to explain or guide the research.
- Farrow, D., Baker, J. & MacMahon, C. (2013). *Developing Sports Expertise: Researchers and Coaches put Theory into Practice (2nd Edition)*. NY: Routledge. – These authors have edited a couple of books on the development of sport skill, which have an applied focus and contain a coach's perspective on empirical research.
- Hodges, N. & Williams, M. (2012). *Skill Acquisition in Sport: Research, Theory, and Practice*. London/ UK: Routledge. – An edited volume with chapters written by experts in various fields related to motor learning and expert performance (see also 2004).
- Klawans, H. L. (1996). Why Michael couldn't hit and other tales from the neurology of sports. London, UK: W.H. Freeman & Company. – A series of case studies, in accessible, non-academic descriptions, to explore the neurophysiology of sport.
- Schmidt, R. & Lee, T. (2011). Motor Control and Learning: A Behavioral Emphasis (5th ed.). – A comprehensive academic textbook on the topic of motor learning and control.

Useful websites and online resources

Academic related:

- Motor Skills Lab (School of Kinesiology, UBC): http://msl.kin.educ.ubc.ca/
- The Creativity Post: http://www.creativitypost.com/authors/profile/8/sbkaufman

- SCAPPS (Canadian Society for Psychomotor Learning and Sport Psychology): www.scapps2014.org/
- NASPSPA (North American Society for the Psychology of Sport and Physical Activity): http://www.naspspa.org/

Skateboard related:

- Christopher Chann (for 5 tips on how to improve your learning) https://www.youtube.com/watch?v=zgt_P2n3Uow as well as: https://www.youtube.com/user/christopherchann
- The Berrics, for a comprehensive collection of skateboarding tricks (especially the “trickipedia” series): http://www.theberrics.com/trickipedia
- Adam Shomsky has a youtube series (skateology) filming skateboarding tricks at 1000 fps. Fantastically useful for beginners. This is his clip for heelflips: https://www.youtube.com/watch?v=ggvnTbBPh-E

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Table 1. Different types of error signals and how they combine to influence learning.

Movement	Error Signal α	Error Signal β	Interpretation
#1	Larger	Larger	The predicted outcome did not occur, neither did the desired outcome. From this error it is not clear if prediction or control processes need to be updated.
#2	Smaller	Larger	The movement produced the desired outcome, but not what was predicted. Prediction processes need to be updated.
#3	Larger	Smaller	The movement resulted in the predicted outcome, but not the desired outcome. Goal selection and/or control processes need to be updated.
#4	Smaller	Smaller	This is a well calibrated movement.

Box captions

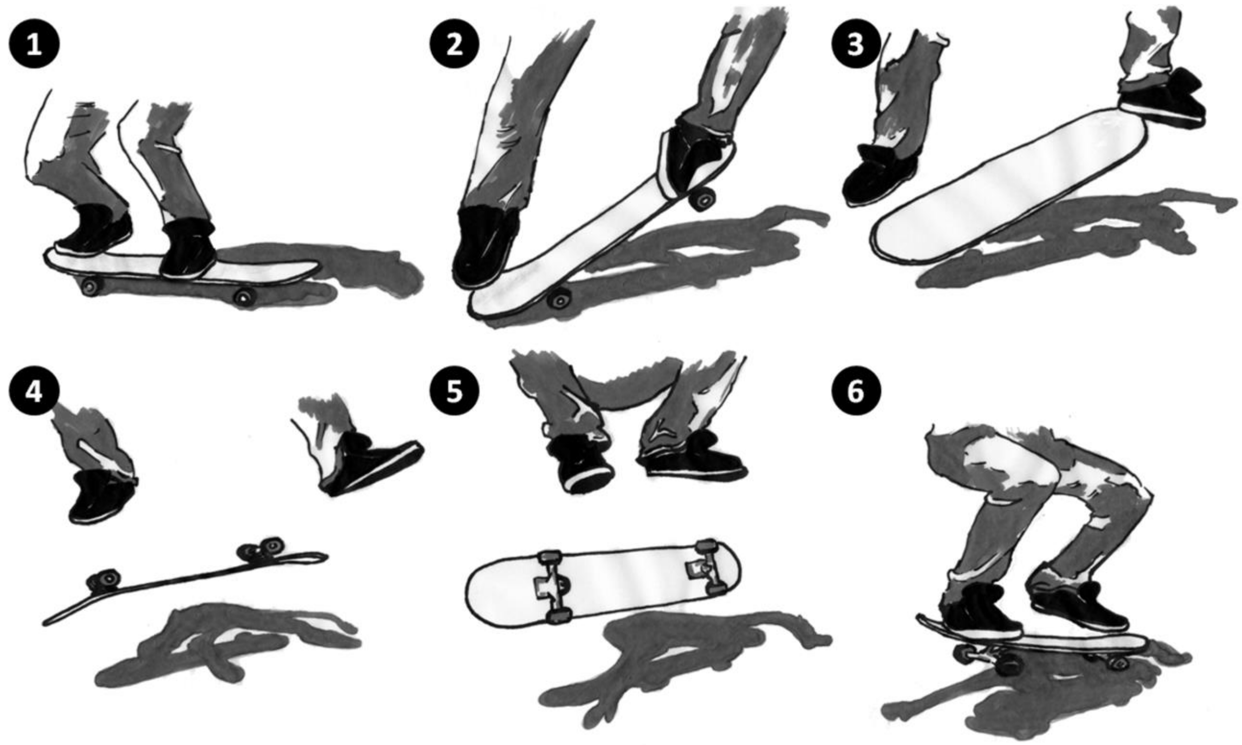
Box 1 (definition/description box). An illustration of select stages of a heelflip. (1) In the approach, the feet are near the back of the board. (2) As the board is propelled off the ground, the forefoot is slid toward the nose of the board. (3) Force is applied to the edge of the board with the foot from a 'kick', which starts the board to rotate around its long axis. (4-5) Momentum carries the board forward as it continues to rotate. (6) As the board completes a 360˚ rotation, the rider lands on the board.

Box 2 (discussion point box). A schematic of a simplified motor system, showing approximate stages (in black boxes) and underlying representations of endogenous processes (in white boxes) involved in motor control. Lines represent abstract transformations that occur between stages. Comparisons (indicated by Xs) between the desired state, predicted state, and the actual state of the motor system (estimated through afferent feedback) generate error signals that can be used to tune perceptual-motor transformations (black arrows between stages). Accurately tuning these transformations so that the actual state reliably resembles the desired state is part of the motor learning process.

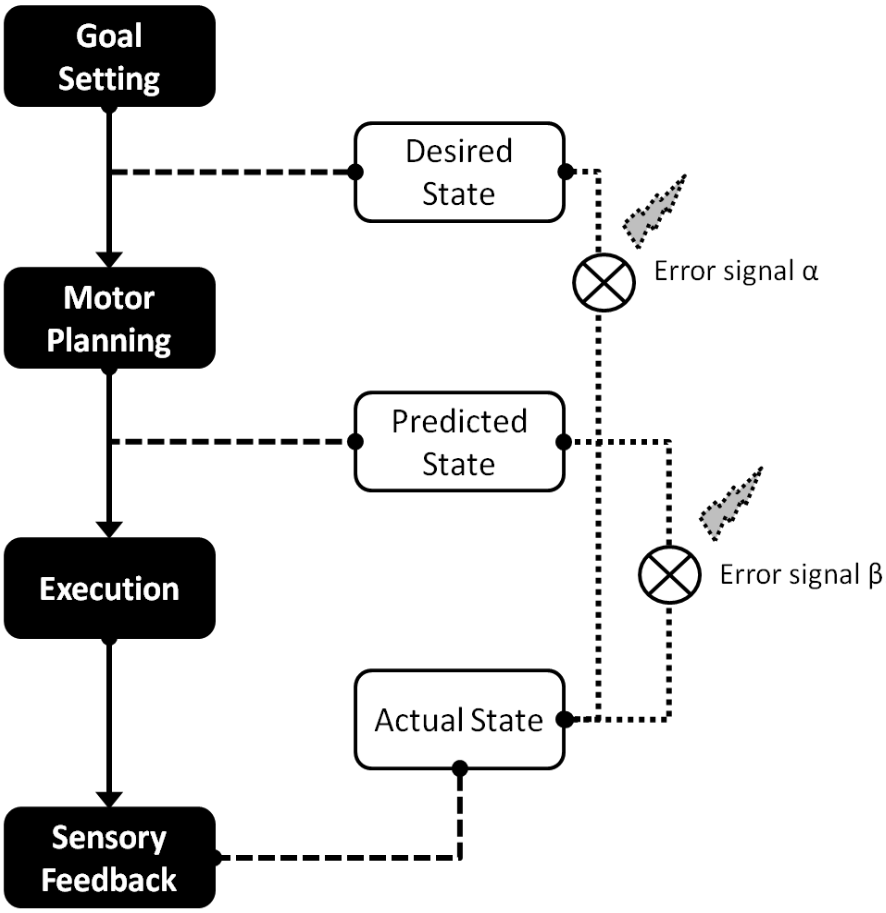
Box 3 (applied implications box). Building on the “endogenous” motor system schematic shown in Box 2, this figure shows how endogenous error signals might be augmented or supplemented by changes to the practice environment. Based on the examples in the chapter we detail how external feedback, video demonstrations, assistive devices, and manipulations to the practice schedule can impact various processes of control. Appropriate application of motor learning principles can improve the quality of error signals and/or how those error signals are used, resulting in accelerated learning. Although the complexity of the motor system is tremendously scaled-down in the figure, we hope to illustrate the applied value of integrating basic science in motor learning and control with the practical tools available to coaches and athletes.

Box 4 (definition/description box): A definition and example of the Contextual Interference (CI) effect.

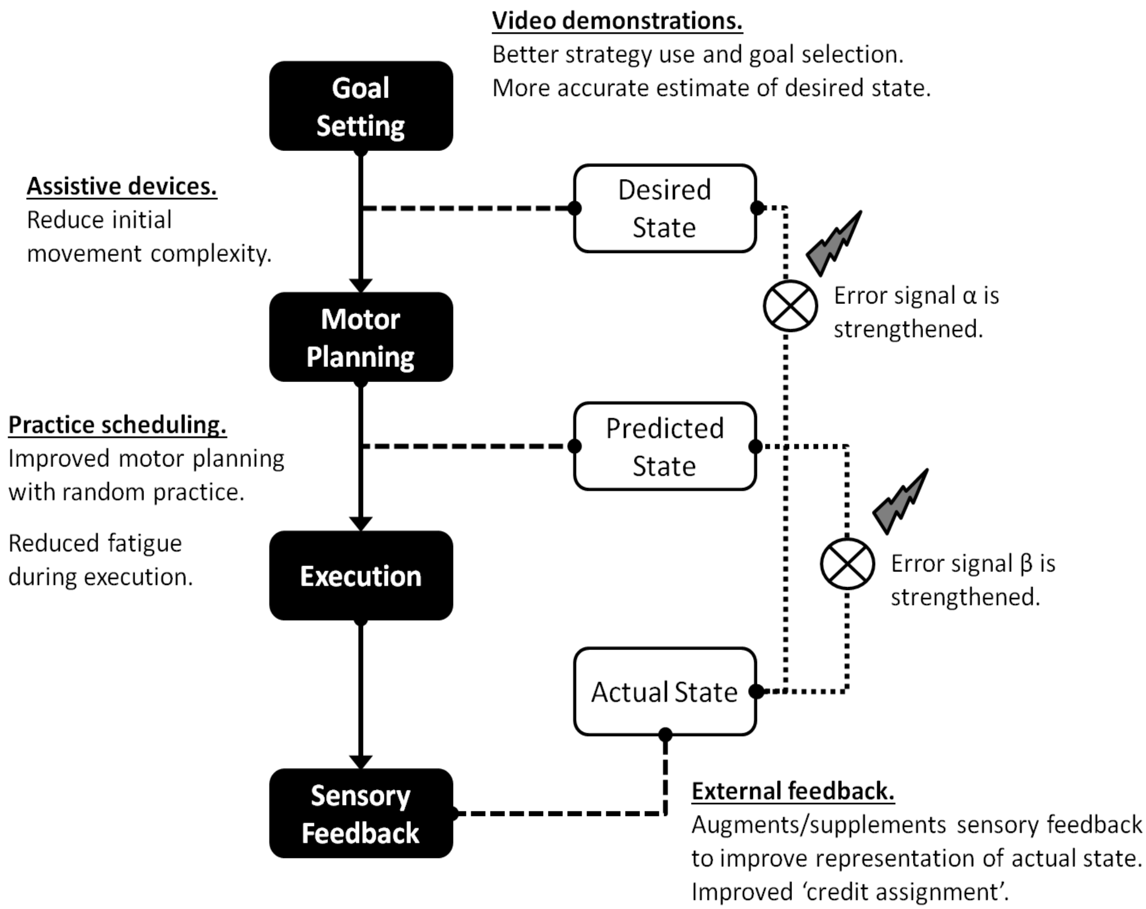
Box 1



Box 2


Goal Setting
Desired State
Error signal α
Motor Planning
Predicted State
Error signal β.
Execution
Actual State
Sensory Feedback

Box 3


Video demonstrations.
Better strategy use and goal selection.
More accurate estimate of desired state.
Goal Setting
Assistive devices.
Reduce initial movement complexity.
Desired State
Error signal α is strengthened.
Motor Planning
Practice scheduling.
Improved motor planning with random practice.
Predicted State
Reduced fatigue during execution.
Execution
Error signal β is strengthened.
Actual State
Sensory Feedback
External feedback.
Augments/supplements sensory feedback to improve representation of actual state.
Improved 'credit assignment'.

Box 4

What is the contextual interference effect?

The Contextual Interference or “CI” effect is a practice organization effect that matters when people need to schedule their practice of multiple, related skills. Essentially, it is a comparison of high-interference practice, characterized by frequent switching across skills or tasks, or what has been termed *random* practice, and low interference practice, characterized by repetitive, *blocked* practice of different skills within or across practice sessions. The easier (low CI) blocked practice, typically results in more obvious performance gains during practice in comparison to the essentially more challenging (high CI) random practice. Importantly, however, these results are reversed when retention is looked at a day or so later. In retention, a more random type of practice results in better long term learning than the easier, low interference schedule.

Example of 2 different types of practice schedules for 3 skills (A,B,C):

Random practice: skill A, skill B, skill A, skill C, skill A, skill C, skill B, skill B, ….

Blocked practice: skill A, skill A, skill A…. skill B, skill B, skill B…. skill C, skill C ….

The “CI” effect was first defined (and illustrated) by Battig (1966) in the verbal learning domain. It has since been replicated numerous times with motor tasks, although the effects do seem to be somewhat dependent on the skills of the learner and the demands of the tasks (for a more recent review see Lee, 2012 as well as Guadagnoli & Lee, 2004).

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